OPTIMIZATION OF FILLCRETE

Alberta
MUNICIPAL AFFAIRS
Innovative Housing Grants Program

[redacted]

OPTIMIZATION OF FILLCRETE

February, 1991

Prepared by:

J.D. Robson, P. Eng.

EBA Engineering Consultants Ltd.

With funding provided by
Alberta Municipal Affairs

ISBN: 0-88654-335-5

Printed on Recycled Paper

FOREWORD

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Innovative Housing Grants Program
Alberta Municipal Affairs
Housing Division
Research and Technical Support
16th Floor, CityCentre
10155 - 102 Street
Edmonton, Alberta
T5J 4L4

Telephone: (403) 427-8150

ACKNOWLEDGEMENTS

The writer wishes to acknowledge the assistance of the following individuals in assembling the background data necessary to do a study of this scope.

Mr. John Ward, P.Eng.	City of Edmonton
Mr. Steve Slobodian, P.Eng.	City of Edmonton
Mr. John Dutton	Alberta Concrete Products
Mr. John Moquin	Consolidated Concrete Limited
Mr. Al Slessor	Western Canada Flyash

TABLE OF CONTENTS

Page No.

LIST OF TABLES

Page No.

LIST OF FIGURES

EXECUTIVE SUMMARY

Many Canadian municipalities have recently been experimenting with and using controlled low-strength materials (CLSM) for backfilling utility trenches. CLSM's are similar to ready-mixed concrete, but the mix components are selected and proportioned to yield an easily excavatable end product.

Recent studies carried out on behalf of the City of Edmonton in conjunction with its Watermain Renewal Program have identified one CLSM, known generically as fillcrete, as the best potential backfill material for that Program. Fillcrete has been used by the City of Edmonton, but the material has two major drawbacks - relatively high material costs and excessive, inconsistent compressive strengths.

The work of this project has addressed the major problems presently associated with fillcrete through laboratory optimization techniques. A lower cost fillcrete mix with predictable performance would find not only increased use in utility renewal programs, but in new utility construction works where insitu material may not be considered acceptable for backfill purposes.

This project was undertaken in three phases. Phase I encompassed the development of preliminary fillcrete mix designs which were anticipated to be satisfactory with respect to cost and performance criteria. Phase II consisted of laboratory trials. In Phase III, the results of the laboratory trials were analyzed, mix designs were optimized and material and placement specifications were developed.

Current literature on CLSM materials indicates that a minimum compressive strength in the order of 50 to 70 kPa is required in order to permit paving operations to proceed. When excavation of the CLSM material may be required at a later date, it is usually necessary to establish a maximum limit for compressive strength. Maximum 28-day compressive strengths ranging from 400 to 1000 kPa have been specified for various CLSM materials. Most literature suggests that unshrinkable fill be placed with a flowable consistency (i.e. slumps in the range of 150 to 250 mm). The City of Edmonton specifies that fillcrete be placed with a plastic consistency, that is, with slump in the range of 75 to 125 mm.

Edmonton area aggregate and ready-mix concrete producers were contacted to establish which locally available materials could potentially be used in the production of fillcrete. Potential fillcrete aggregates were identified as fine concrete aggregate, crusher elimination sand, and bottom ash. Fillcrete is currently produced using Portland Cement and classified flyash as the cementing materials. Unclassified flyash and lime were identified as possible alternate cementing materials.

Preliminary mix designs were developed for the potential fillcrete aggregates based on the current City of Edmonton specifications.

Initial laboratory trials evaluated the effect of changing the slump of a fillcrete mix by varying the mix water content, as well as, the effect of utilizing air entraining and water reducing admixtures. This was accomplished by producing a series of fillcrete mixes using fine concrete aggregate and a fixed cementing materials content of 40 kg/m^3 of Type 10 (Normal) Portland Cement and 60 kg/m^3 of classified flyash. The initial laboratory trials established that the performance of fillcrete was optimized when it was produced with a plastic consistency using a water reducing admixture and air entrainment.

Further laboratory trials were performed to investigate the use of potential alternate aggregates and cementing materials. Fillcrete mixes were produced using crusher elimination sands instead of the fine concrete aggregate currently specified by the City of Edmonton. These laboratory trials confirmed that acceptable fillcrete can be produced with poorer quality, lower cost aggregate. Trial mixes produced with bottom ash from the Wabamun Power Plant also performed acceptably and further investigation of this aggregate is recommended. The trial mixes produced with alternate cementing materials failed to perform acceptably.

The laboratory trials determined that acceptable fillcrete was not produced when standard cementing materials content of 40 kg/m^3 of Portland Cement and 60 kg/m^3 of Classified Flyash were varied significantly. The existing City of Edmonton specification for an air entrained fillcrete with a slump of 100 $\pm$ 25 mm produces the most workable fillcrete. Based on laboratory trials, the currently specified maximum 28-day compressive strength of 600 kPa is sufficient to ensure the long-term excavatability of fillcrete. Field excavatability trials are still required.

The existing fillcrete mixes can be optimized by substituting a low cost elimination sand for the fine concrete aggregate currently used. The use of elimination sand (or bottom ash) in fillcrete would also conserve the limited amounts of fine aggregate suitable for use in the production of conventional concrete.

The materials used to produce the existing fillcrete mixes cost from $22.43 to $23.72 per cubic metre. The cost of batching and delivery of fillcrete is approximately $9.25 per cubic metre. The use of an elimination sand rather than fine concrete aggregate would result in a savings of $2.71 to $6.03 per cubic metre, or 11 to 27 percent of the current materials cost. In 1989 and 1990, lowering the cost of fillcrete by $3.00 per cubic metre would have saved the City of Edmonton a total of $219,000. This cost saving, although substantial, is not sufficient to justify the use of fillcrete for trench backfill on new construction and other sites where the excavated soil is suitable for recycling as trench backfill.

Fillcrete is most suited to use on projects involving renovation and/or reconstruction where the excavated soil is unsuitable for use as backfill. When imported backfill is required to replace excavated soil, the higher material cost of fillcrete can easily be offset by its convenience, reduced labour costs and assured performance.

This study has established design parameters and construction specifications for the optimized fillcrete mix. It has been determined that the material cost of fillcrete can be reduced significantly by the use of lower quality aggregates. Long term excavatability can be ensured by limiting compressive strength to a maximum of 600 kPa at an age of 28 days and 1500 kPa long term.

1.0 INTRODUCTION

Many Canadian municipalities have utilized Controlled Low Strength Materials (CLSM) for backfilling utility trenches. CLSM materials are produced and utilized in a manner similar to ready-mixed concrete, but the mix components are proportioned to produce an "unshrinkable fill" which can be excavated with power equipment. In the Edmonton area, unshrinkable fill is known as "fillcrete".

The objective of this study was to develop fillcrete mix designs anticipated to be satisfactory with respect to performance and cost. Preliminary fillcrete mix designs were developed based on a review of the available materials. Laboratory trials were used to evaluate these mix designs. Based on the results of the laboratory trials, optimized fillcrete mix designs have been developed.

The initial task was a review of the current literature on CLSM and unshrinkable fill. Edmonton area aggregate and ready-mix concrete producers were then interviewed to establish whether locally available materials could potentially be used in the production of fillcrete.

Potential fillcrete aggregates are: fine concrete aggregate, crusher elimination sand, and bottom ash. Fillcrete is currently produced using Portland cement and classified flyash. The prospective constituent materials for incorporation into fillcrete mixes are described in Section 2.2.

Optimum performance and cost criteria for fillcrete mixes have been established. The available literature indicates that a minimum compressive strength in the order of 50 to 70 kPa is required in the short term in order to permit paving operations to proceed. Because CLSM's continue to gain strength for a considerable period of time, current practice is to specify a maximum 28-day compressive strength ranging from 400 to 1000 kPa to ensure unshrinkable fill can be excavated with power equipment. These strengths are considerably lower than those normally specified for Portland cement concrete.

Most literature suggests that unshrinkable fill be placed with a

flowable consistency (i.e. slumps in the range of 150 to 250 mm). The City of Edmonton specifies that fillcrete shall be placed with a plastic consistency (i.e. slump of 75 to 125 mm). It was anticipated that air entrained fillcrete with a plastic consistency would have the best performance with respect to lack of segregation and shortest setting time. Preliminary fillcrete mix designs were developed based on the City of Edmonton specifications.

During the laboratory trials, a series of twenty-five (25) different fillcrete mixes were produced to evaluate both the mix design assumptions and the use of alternate fillcrete aggregates. Based on the results of the laboratory trials, optimized fillcrete mix designs and mix specifications were developed and an economic analysis of the optimized mix design was performed.

This report presents the results of the CLSM literature survey. Potential constituent materials, including locally available aggregates and cementing materials, are discussed. Performance criteria are established to define important factors such as workability, set time, and excavatability. The cost of fillcrete as produced using the various prospective aggregates and cementing materials is examined. A series of trial batches were prepared to investigate the optimization of fillcrete mixes and the results of testing on the constituent materials and fillcrete are presented. Based on the laboratory trial batches, the optimized fillcrete mix design and suggested specifications for fillcrete mix design and placement are developed and the potential cost savings analyzed.

2.0 PROSPECTIVE MATERIALS

2.1 Background

CLSM's have been produced using a wide variety of cementing materials and aggregates. Portland cement, classified flyash, unclassified flyash and lime have been used as cementing materials. Flyash, coarse and fine concrete aggregates, pit run sand, crusher elimination sand, lightweight aggregates and foaming agents have been used as aggregate and/or fillers.

In Canada, CLSM's used for the backfilling of utility trenches are generally referred to as unshrinkable fills (although the City of Edmonton uses the name "fillcrete"). Typically, unshrinkable fills are produced with concrete aggregates and Portland cement, with the possible addition of a supplemental cementing material such as flyash.

The City of Edmonton specifies that fillcrete be produced with fine concrete aggregate and Portland cement. Classified flyash is used as a supplemental cementing material.

The Regional Municipality of Metropolitan Toronto (Metro Toronto) specifies that unshrinkable fill be produced using fine and coarse concrete aggregate. Toronto prohibits the use of pozzolanic mineral admixtures (such as flyash) in order to limit the long-term compressive strength of unshrinkable fill.

The City of Winnipeg has been a pioneer in the use of unshrinkable fill. The current Winnipeg specification for unshrinkable fill specifies a mixture of sand, cement and water with a maximum cement content of 70 kg/m^3.

Winnipeg's experience with unshrinkable fill indicates that a major cause of excessive strength is the inclusion of small amounts of waste concrete in the unshrinkable fill. Consequently, it is important that all concrete be emptied from the ready-mix truck before the fillcrete is batched. The City of Winnipeg specifies that unshrinkable fill be produced

with sand. This permits field inspectors to use the presence of coarse aggregate in the mix as an indication that the load includes ready-mix concrete and that excessive strengths may result.

The following sections outline the alternate materials that were identified as potential fillcrete constituents.

2.2 Aggregates

2.2.1 Natural Aggregates

Aggregate resources in the Edmonton area generally consist of deposits of gap-graded sandy gravels or gravelly sands with a relatively high fines (material passing the 0.080 mm sieve) content. These deposits tend to be deficient in coarse sand and fine gravel sized particles. The locally available pit run sands are typically uniformly graded fine sands with a trace to some silty fines. Local aggregate deposits frequently contain significant amounts of soft rock types, such as coal and clay ironstone, which are considered deleterious substances for use in concrete.

When processing the local gap-graded aggregate deposits to produce well graded sand and gravel mixtures, such as asphalt or road base aggregates, it is necessary to eliminate excess sand. Typically, crusher feed aggregate is screened on a 10 or 12.5 mm slotted deck to separate the sand from the gravel prior to crushing the gravel. The sand eliminated from the crusher feed (elimination sand) tends to be better graded (and more compactable) than the typical uniformly graded pit run sand. At some pits, aggregate producers are able to sell the elimination sand for use as fill sand. Elimination sand is also sold for use as blend sand in asphalt concrete production. However, at a number of pits, the supply of elimination sand exceeds the demand and it has been necessary to bury large amounts of

elimination sand to prevent the stockpiles from interfering with pit reclamation.

2.2.1.1 Fine Concrete Aggregate

In the Edmonton area, the absence of deposits of clean, well graded sand, free of deleterious materials means that a significant amount of washing and processing is required to produce a fine concrete aggregate satisfying the CAN/CSA-A23.1-M90 specifications.

The City of Edmonton has permitted fillcrete suppliers to use fine concrete aggregates which do not completely satisfy the requirements of CAN/CSA-A23.1-M90. However, the fillcrete sand is still required to have a minimum fineness modulus (FM) of 2.3 and a maximum fines content of 3 percent. Permitting the use of a lower quality sand in the production of a low strength material such as fillcrete allows the more limited supply of high quality sand to be conserved for use as fine aggregate in concrete production.

2.2.1.2 Elimination Sand

There is an abundant supply of elimination sand in the Edmonton area. Similar aggregates have been used to produce CLSM's for general backfilling applications. Local aggregate producers were contacted, and typical product gradations, supplied by them, are presented in Table 1.

2.2.2 Bottom Ash

Ash is the by-product of the burning of pulverized coal in electric generating stations. The majority of the ash is composed of fine particles which are transported from the combustion chamber by suspension in the exhaust gases and subsequently collected as flyash. The coarser portion of the ash which accumulates at the bottom of

TABLE 1

Edmonton Area Elimination Sand Products

Aggregate Supplier	Agggregate No.	Aggregate Source (Sample Description)	Percent Passing Sieve (mm)															Cost/tonne (FOB pit)	Est. Haul Cost (per tonne)	Total cost (per tonne)
			20.0	16.0	12.50	10.00	5.00	2.50	2.00	1.25	0.800	0.630	0.400	0.315	0.160	0.080	0.063			
TBG Contracting Ltd.	1	Pit 4 - Cloverbar Pit (crusher screenings)			100.0	100.0	93.2			78.6		67.5		29.9	10.8	6.5		$3.00	$2.35	$5.35
	2	Pit 11 - Onoway (natural screenings)	100.0	99.6	96.6	91.7	74.9	69.0		65.4	63.5		46.0		14.2	8.7		$2.15	$4.00	$6.15
	3	Pit 21 - Sema Pit (natural screenings)			100.0	97.0	89.6	86.5		83.4		59.7		29.9	14.9	9.8		$1.75	$3.60	$5.35
	4	Pit 80 - Sime Pit (natural fines)			100.0	95.2	79.3	70.0		62.0		53.0		31.0	11.0	7.5		$2.75	$4.25	$7.00
Standard General Construction Limited	5	Riverview Pit (natural fines)	100.0		96.4	93.9	88.6		80.7		71.2		46.1		13.2		7.2			$5.00
Consolidated Concrete Limited	6	Pit 45 - Villeneuve (bank sand unwashed)			100.0	100.0	97.9	97.2		96.5		94.6		51.6	10.4	2.4				$5.00
	7	Pit 46 - General Pit (elimination sand)		100.0	95.4	84.5	69.5	64.1		60.9		57.3		30.8	9.5	4.0				$6.00
	8	Pit 48 - Nesbit Pit (asphalt elimination)		100.0	94.9		81.1				69.5						9.4			$6.00
O.K. Construction Materials	9	Pit 24 - Nesbit Pit (elimination sand)			100.0	97.5	86.0				73.0		56.9		14.2		5.2	$2.20	$3.34	$5.54
	10	Pit 10 - Evergreen Pit (elimination sand)			100.0	98.7	88.0		80.7		70.7		41.8		7.8		4.7	$3.00	$2.27	$5.27
	11	Pit 56 - Villeneuve Pit (blend sand)		100.0	99.1	96.1	82.3			69.5		65.2		46.4	26.5	18.3		$2.00	$2.42	$4.42
	12	Pit 56 - Villeneuve Pit (natural sand)			100.0	99.6	94.5			85.8		82.1		45.8	9.7	3.3		$2.00	$2.42	$4.24

the furnace is called bottom ash. The bottom ash is typically composed of well graded sand, or sand and gravel sized particles.

Currently, there is no commercial utilization of bottom ash produced in the Edmonton area. Bottom ash is simply wasted into depleted areas of the open pit mines prior to site reclamation.

Bottom ash produced at the Sundance and Wabamun power plants has a nominal particle size of 10 to 12.5 mm, and the grain size distribution of a well graded sand with some gravel. The grain size analysis of samples of bottom ash received from Western Canada Flyash (Samples 3014.1, 3014.2, 3019) are presented in Figures 1 to 3. The bottom ash gradings are slightly coarser than CSA fine aggregate grading requirements, but appear suitable for use in fillcrete production.

The density of bottom ash is considerably less than that of a natural sand. Local sands typically have a saturated surface dry (SSD) bulk relative density of approximately 2.6, while bottom ash from the Sundance Power Plant (Sample 3014.2) had an SSD relative bulk density of 2.0. The particles of bottom ash are quite friable and some particles can be hand crushed. The low compressive strength of the bottom ash particles likely limits the potential for long term strength gain of fillcrete produced with bottom ash.

Bottom ash also has a lower coefficient of thermal conductivity than natural sands and, hence better insulating characteristics. It therefore appears likely that frost penetration through fillcrete produced with bottom ash would be reduced in comparison to that of fillcrete produced with natural sand.

Recent monitoring by the City of Edmonton and Consolidated Concrete Limited (Dilger and Goodrich) indicates that the depth of frost penetration in

fillcrete is approximately 1½ times the depth of frost penetration in the adjacent insitu clay. Consequently, the potential benefits of a fillcrete mix with reduced thermal conductivity using bottom ash are considerable.

2.3 Cementing Materials

Portland cement, classified flyash, unclassified flyash and lime have been used as cementing materials in the production of CLSM's.

Portland cement is the most common cementing material. It has a relatively rapid rate of strength gain, which tends to minimize the long term compressive strength at ages in excess of 28-days. Metro Toronto prohibits the use of pozzolanic mineral admixtures (such as flyash) in order to limit the long-term compressive strength of unshrinkable fill.

The City of Winnipeg specifies a maximum cement content of 70 kg/m^3 for unshrinkable fill. Unlike Toronto, Winnipeg permits the use of flyash as a supplemental cementing material. Currently, Winnipeg is experimenting with the production of fillcrete without Portland cement. The experimental mix uses approximately 170 kg/m^3 of flyash.

Fillcrete in the Edmonton area is produced using Type 10 (Normal) Portland cement and classified flyash as the cementing materials. Unpublished data from the City of Edmonton indicates that there are significant gains in fillcrete compressive strength after an age of 28-days. The average 112-day compressive strength was 2⅛ times the 28-day compressive strength.

A number of projects have been constructed in the United States and Great Britain using flyash based slurries. Most of these projects have been done in close proximity to the flyash source. Relatively small amounts of Portland Cement or lime have been used as activating agents for flyash slurries. However, the need for an activating agent is strongly influenced by the chemistry of the flyash used.

3.0 PERFORMANCE CRITERIA

Fillcrete and other unshrinkable fills are designed to produce a material that:

- is easy to handle and place in a trench (workability).
- provides a stable subgrade for pavement construction in a relatively short period of time (set time).
- can be excavated with power trenching equipment should the need arise (excavatability).

The following sections discuss the criteria for evaluating the performance of fillcrete.

3.1 Workability

Workability is the property of a freshly mixed concrete or mortar that determines the ease and homogeneity with which it can be produced, placed and consolidated. Fillcrete should be easy to produce, easy to place, have minimum tendency to segregate and/or bleed, and be easy to consolidate.

Fillcrete should have a flowable consistency to ensure that trench backfill is free of voids behind shoring or underneath overhangs. A flowable consistency can be achieved by proportioning the mix to obtain a slump in the order of 150 to 200 mm or more. It can also be accomplished by using vibration to fluidize and consolidate a mix with a plastic consistency, i.e. a slump of 75 to 125 mm.

It is slightly more difficult to place a mix with a plastic consistency as the contractor should use a vibrator. Fortunately, most fillcrete mixes are somewhat thixotropic, and very little effort is required to fluidize the mix. A plastic mix can be produced with reduced amounts of mix water, and will generally experience less segregation, reduced bleeding, and more rapid setting times.

Concrete admixtures such as water reducing and air entraining agents can also be used to modify the consistency of a

fillcrete mix. A water reducing admixture can be used to disperse the cementing materials and reduce the quantity of mixing water required to produce a mix of a given slump. This generally results in an increase in strength. In an air entrained mix, the large number of well distributed, disconnected air voids increase the workability of the mix, while reducing bleeding and segregation. For a given slump, an air entrained mix will require less water than a non-air entrained mix made with the same aggregate.

For exposed concrete, air entrainment sufficient to produce an air void system with adequate size and spacing of air voids is essential to produce a material that is durable when exposed to cycles of freezing and thawing. Because fillcrete is a low strength material which is covered by the pavement structure after installation, it is not subjected to the same weathering forces during freeze-thaw cycles, nor is it required to have the same freeze-thaw durability. There is no consensus that air entrainment is necessary, or sufficient, to ensure freeze-thaw durability of unshrinkable fill. Fillcrete, therefore, should only be air entrained as required to improve workability. A minimum air content of 4 percent is suggested as sufficient to improve workability. This is approximately twice the natural entrapped air content of 1 to 2 percent.

During the laboratory trials, mixes were produced both with and without air entrainment, with and without a water reducing admixture, and at a variety of slumps between 75 and 200 mm. This made it possible to evaluate the impact of slump, air content and the use of a water reducing admixture on the workability, potential for segregation, bleeding and setting time of fillcrete.

3.2 Set Time

Set time is the time required for the fillcrete mix to achieve a compressive strength sufficient to allow paving operations to proceed. It is understood the City of Edmonton Public Works Department requires fillcrete to achieve its initial set

within approximately 48 hours. Metro Toronto specifies that unshrinkable fill achieve a minimum 1-day compressive strength of 70 kPa in order to achieve a setting time suitable for their purposes. It is estimated that a minimum compressive strength of approximately 50 kPa would be sufficient to permit paving operations to proceed. The 50 kPa strength should be achieved within one or two days.

3.3 Excavatability

A major concern with the performance of unshrinkable fill is the ability to limit the long term compressive strength of the material sufficiently to ensure that it can be excavated with conventional power equipment. Unlike most other concrete materials, unshrinkable fill does not generally have a minimum specified 28-day compressive strength. Rather, a maximum 28-day compressive strength is specified in order to control the long term strength.

There is limited data concerning the maximum allowable compressive strength to ensure excavatability. Maximum 28-day compressive strengths have been variously specified at anywhere from 400 to 1000 kPa. However, these specifications are based on the long term strength of unshrinkable fills, which are known to be more than double the 28-day compressive strength. Unpublished data from the City of Edmonton indicates that the long term strength of fillcrete will likely be in the order of 2½ times the 28-day compressive strength. It has been recommended that the City of Edmonton conduct field trials to determine the limiting maximum compressive strength for conventional excavation.

In the absence of design guide-lines for establishing long term compressive strength, 2000 kPa was used as the provisional cut-off for maximum allowable long term strength. It is expected that fillcrete with a compressive strength in excess of approximately 2000 kPa will be difficult to excavate without using a concrete breaker.

During the laboratory evaluation of excavatability of the

trial fillcrete mixes, the compressive strength of the fillcrete was correlated to the ability of a hand auger to penetrate the mix. The auger was loaded to simulate the force applied by the tooth of a standard hydraulic backhoe bucket.

3.4 Quality Control

Experience indicates that a major cause of excessive fillcrete strengths is the inclusion of small amounts of waste concrete in the fillcrete. The City of Winnipeg now specifies that unshrinkable fill be produced with sand. This permits the presence of coarse aggregate in the mix to be used as an indication that the load includes ready-mix concrete. It is therefore recommended that fillcrete be produced with a 10 mm nominal sized aggregate.

The nominal aggregate size is equal to the sieve size on which less than 10 percent of the material is retained. The nominal aggregate size is usually smaller than the maximum aggregate size (the smallest sieve size through on which no material is retained). Therefore, a 10 mm nominal sized aggregate may have a maximum aggregate size of 14 mm, but must have less than 10 percent retained on the 10 mm sieve.

The slump test (CSA A23.2-5C) is the standard measure of the workability of a concrete mixture. As mixes become flowable rather than plastic (i.e. slumps in excess of 180 mm), the slump cone provides a less accurate measure of workability. Alternate means of measuring the workability of flowable mixes were examined during the laboratory trials.

3.5 Summary of Performance Criteria

The fillcrete performance criteria and initial design mix target properties are summarized as follows:

- Plastic Consistency, Slump of 100 mm ±25 mm
- Air Entrainment for Workability, Air Content of 5% ±1%
- Maximum Setting Time: 2 days
- Maximum 28-day Compressive Strength: 600 kPa
- Maximum Long-Term Compressive Strength: 2000 kPa

4.0 COSTS

An objective of this study was to evaluate means of improving the economics of fillcrete. The economics of fillcrete are a function of both performance and cost. The cost of fillcrete can be divided between the cost of materials used in the production of fillcrete (aggregate, cementing materials and admixtures) and the relatively fixed cost of production and hauling. For purposes of this cost analysis, the following assumptions have been made.

- All aggregate costs are December, 1989 costs based on delivery to the northwest industrial area of Edmonton. Alberta Concrete Products, Canadian Concrete Products, Consolidated Concrete Limited and Stel-Marr Concrete Ltd. all have batch plant facilities in the vicinity of 118 Avenue and 149 Street.

- Changing the materials used to produce fillcrete may require modifications to the existing batch plants. It has been assumed that the cost of the necessary modifications could easily be amortized over a one year contract for fillcrete supply to the City of Edmonton.

4.1 Aggregate

Currently, fillcrete is produced using a processed fine aggregate very similar to fine concrete aggregate. The potential alternates to fine concrete aggregate are elimination sand and bottom ash.

Coarse concrete aggregate has not been considered for use in fillcrete for two reasons. Coarse concrete aggregate is considerably more costly than fine concrete aggregate. Only a few pits have gravel sufficiently free of deleterious material to permit processing as coarse concrete aggregate. Also, producing fillcrete with sand sized aggregate permits field inspectors to use the presence of coarse aggregate in the mix as an indication that the load contains ready-mix concrete.

Local aggregate producers were contacted to obtain the approximate cost of fine concrete aggregate and elimination sands. The December, 1989, cost of fine concrete aggregate ranged from $8.00 to $8.75 per tonne. The December, 1989, cost of elimination sand ranged from $4.25 to $7.00 per tonne, with the majority of the products in the range of $5.00 to $6.50 per tonne.

The total cost of bottom ash is estimated to be approximately $11.80 per tonne. This cost can be broken down as follows: Hauling the bottom ash approximately 65 km from the Wabamun Power Plant would cost approximately $8.30 per tonne. It is estimated that it would cost an additional $1.00 per tonne to screen and load the bottom ash onto the trucks. A nominal pit royalty of $2.50/tonne has been assumed, for a total cost of $11.80 per tonne. Even though the cost per tonne of bottom ash is significantly higher than the fine concrete aggregate its use as an aggregate in fillcrete can still be considered because its lower specific gravity results in a similar cost per cubic metre of fillcrete.

Bottom ash is a waste product. The sale of bottom ash eliminates the expense of hauling it back into the coal mine for disposal. Consequently the pit royalty (market price) for bottom ash, F.O.B. plant, would be entirely demand driven. The availability of bottom ash from the City of Edmonton's Genesee power plant would provide a limiting factor on the market price.

The December, 1989 costs for the potential alternate fillcrete aggregates are summarized in Table 2.

For purposes of this preliminary cost analysis, it has been assumed that all of the potential fine aggregates could be used to produce a fillcrete of acceptable performance and that changing the type of aggregate used in the mix will not affect the cementing materials content, admixture dosage rates or other costs of the mix.

Table 2
Aggregate Costs

Aggregate	Cost	Preliminary Estimate Mix Design Quantity	Estimated Cost
	(per tonne)	(tonne/m^3)	(per m^3)
Fine Concrete Aggregate	\$8.00 - 8.75	1.65	\$13.20
Elimination Sand	\$5.00 - 6.50	1.65	\$8.25 - 10.73
Bottom Ash	\$11.80	1.05	\$12.39

Based on the stated assumptions, the use of elimination sand rather than fine concrete aggregate would permit a materials cost saving in the order of \$2.50 to \$5.00 per cubic metre. The use of bottom ash would result in a materials cost saving of approximately \$0.80 per cubic metre.

If satisfactory fillcrete can be produced using either elimination sand or bottom ash, it is likely the increased demand for these materials will drive costs up closer to the cost of fine concrete aggregate. Consequently, it is likely that in the long term, the economics of using fillcrete will be driven as much by the performance of the mix as by the material costs of the mix.

4.2 Cementing Materials

Currently, fillcrete is produced using classified flyash and Portland cement as cementing materials. Portland cement costs \$140.00 per tonne. Classified flyash costs \$40.00 per tonne. It is produced by using a cyclone classifier to remove larger sized particles, reducing variability in particle size and loss-on-ignition. To minimize the cost of cementing materials, producers attempt to minimize the PortlandcCement content of fillcrete and maximize the use of classified flyash as a supplemental cementing material. Because of the slower

strength gains associated with the use of flyash, this practice tends to result in longer setting times and increased long term strengths.

Unclassified (unprocessed) flyash has been successfully used in unshrinkable fills and flyash slurries. It is not currently available in the Edmonton area, but Western Canada Flyash projects the cost of unclassified flyash as $30.00 per tonne. The use of unclassified flyash would represent a potential cost saving of $0.60 per cubic meter of fillcrete (60 kg/m^3 x $10.00/tonne). However, the economics of using unclassified flyash in fillcrete do not appear favourable. The unclassified flyash must not be permitted to cross-contaminate the cementing materials used in the production of regular concrete mixes. Consequently, a separate batch plant would probably be required. Also, the variability of unclassified flyash would likely influence the setting time and other performance characteristics of the fillcrete mix, making it more difficult to adequately control production.

One possible means of reducing the cost of cementing materials would be to use hydrated lime rather than Portland Cement to activate flyash as a cementing material. Flyash reacts with the lime (CaO) liberated during the hydration of Portland Cement. This is one of the reasons for the slower strength gain of flyash mixes. It has been hypothesized that a more rapid strength gain could be realized by adding free lime to the mix. Although either quick lime (CaO) or hydrated lime $Ca(OH)_2$ could be used, the latter product is more readily available.

Because hydrated lime contains more lime than is liberated by the hydration of Portland Cement, the amount of hydrated lime required as an activating agent should be in the order of 20 to 25 percent of the amount of Portland Cement. Although hydrated lime, delivered in bulk as a powder, costs $141.30 per tonne (or essentially as much as Portland Cement), the reduced batch quantities could result in an appreciable cost saving. Unfortunately, as reported in Section 7.0,

preliminary trials indicated that the use of lime and flyash as the cementing material will lead to excessive setting times.

The preliminary analysis indicates that there are no major cost savings to be realized by using alternate cementing materials. Initial laboratory trials were therefore carried out using standard cementing materials contents of 40 kg/m^3 of Type 10 (Normal) Portland Cement and 60 kg/m^3 of classified flyash.

4.3 Projected Cost of Optimized Fillcrete Mix

Based on the previously stated assumptions, the cost of the optimized fillcrete mix can be projected as follows:

o	Aggregate	\$8.25 to \$13.20 per cubic metre
o	Portland Cement	\$4.90 to \$6.30 per cubic metre
o	Classified Flyash	\$2.20 to \$2.60 per cubic metre
o	Admixtures	\$0.45 per metre

The projected cost of an optimized fillcrete mix ranges from \$16.20 to \$22.15 per cubic metre. The projected cost of an optimized fillcrete mix produced with fine concrete aggregate and the standard cement materials content is \$21.65 per cubic metre.

5.0 PRELIMINARY FILLCRETE MIX DESIGNS

5.1 Aggregate

Three types of aggregate have been identified for potential use in fillcrete production: Fine Concrete Aggregate, Elimination Sand and Bottom Ash.

The grading limits suggested for fillcrete aggregate are presented in Table 3. The corresponding CAN/CSA A23.1-M90 fine concrete aggregate grading requirements are presented for comparison.

Table 3
Suggested Grading Requirements for Fillcrete Aggregate

Sieve Size	Percent Passing by Weight	
	Fillcrete Aggregate	Fine Concrete Aggregate CSA-A23.1-M90
14 mm	100	100
10 mm	90 - 100	100
2.5 mm	65 - 100	80 - 100
0.630 mm	25 - 80	25 - 65
0.080 mm	0 - 10	0 - 3

The suggested grading requirements are significantly less stringent than the CSA A23.1 fine concrete aggregate grading requirements. The specified maximum amount of material retained on the 10 mm sieve has been increased to 10 percent. This may reduce the amount of screening required. It will allow the use a larger opening size on the screening deck, which will make screening easier. The grading requirements also increase the maximum allowable fines content from 3 percent to 10 percent, which will reduce or eliminate the requirement for washing of fillcrete aggregate.

For purposes of this study, it was decided to evaluate the potential for using elimination sand products for which there

is currently limited demand. These included Aggregates Nos. 2, 3, 5, 6, 7, 8, 11, and 12 as designated on Table 1 (page 6).

Aggregates 7, 12, and 13, from pits in the Villeneuve area, consist primarily of uniform fine sand and were, therefore, eliminated from further consideration.

The gradations of the remaining sands are generally similar. In order to examine the spectrum of potential sand sources, it was decided to evaluate a typical fine graded aggregate and a relatively coarsely graded aggregate.

Aggregate No. 3, screened elimination sand from the Serna Pit (ESS), has a fines content of 9.8 percent. This material probably represents the finest aggregate which could be used.

Aggregate No. 7, elimination sand from the General Pit (ESG), has a relatively coarse grading and contains less than 5 percent fines. This material has previously been used by Independent Transit Mix to produce fillcrete for Northwestern Utilities Limited.

The ESG has a nominal aggregate size of 12.5 mm, which is slightly larger than the suggested 10 mm nominal aggregate size. For the laboratory trials, aggregate No. 7 was dry screened on the 10 mm sieve to produce an aggregate satisfying the suggested grading requirements.

The sample of bottom ash from the Wabamun Power Plant received from Western Canada Flyash also contained a small amount (2.1 percent) of material retained on the 14 mm sieve. The bottom ash was also screened on the 10 mm sieve to remove oversize material for the laboratory trials.

Prior to undertaking laboratory trial mixes, samples of fine concrete aggregate, elimination sand and bottom ash were obtained from their respective suppliers. The aggregate samples were tested to determine grain size distribution,

colour plate, bulk density, relative density and absorption. This information was used to develop the fillcrete mix designs used for the laboratory trials.

5.2 Preliminary Mix Designs

Prior to the laboratory trials, there were unresolved questions regarding the consistency of fillcrete as it is currently produced. It was anticipated that air entrained fillcrete with a plastic consistency would have the best performance with respect to lack of segregation, workability, and shortest setting time.

The first phase of the laboratory trials was conducted using fillcrete produced with fine concrete aggregate, 40 kg/m^3 of Portland Cement and 60 kg/m^3 of classified flyash. These trials were used to establish the guidelines for achieving satisfactory fillcrete performance. Trial mixes were produced to investigate the influence of the following parameters:

- Slump
- Air Content
- Use of a Water Reducing Admixture
- Use of Vibration for Consolidation

The results of these tests were used to establish the design values for slump and air content of fillcrete. Trial mixes were then prepared using elimination sand and bottom ash to evaluate the performance of these alternate aggregates in fillcrete.

Historically, natural sands in the Edmonton area have a saturated surface dry (SSD) relative density of approximately 2.60 with an absorption of approximately 1 to 2 percent. Testing of bottom ash from the Sundance Power Plant indicates it has a relative density of approximately 2.00 with an absorption in the order of 6 percent. Based on this information, the preliminary mix designs were developed and are presented in Table 4.

TABLE 4
Preliminary Fillcrete Mix Designs

Material	Mix 1 (kg/m³)	Mix 2 (kg/m³)	Mix 3 (kg/m³)	Mix 4 (kg/m³)
Water	285	285	285	500
Portland Cement	40	40	40	40
Classified Flyash	60	60	60	60
Fine Concrete Aggregate (FCA)	1650			
Elimination Sand, Serna (ESS)		1650		
Elimination Sand, General (ESG)			1650	
Bottom Ash, Wabamun (BAW)				1050
Yield, kg/m^3	**2035**	**2035**	**2035**	**1650**

Note: All aggregates proportioned on SSD basis to yield 1.00 m^3 at the minimum air content of 4 percent.

Initial Design Mix Target Properties:

Slump, mm $\pm$ 25 mm	100
Air Content, % $\pm$ 1%	5
Maximum Setting Time, Days	2
Maximum 28-Day Compressive Strength, kPa	600
Maximum Long-Term Compressive Strength, kPa	2000

Bleeding: Controlled to limit migration of cementing materials.

6.0 MATERIAL PROPERTIES

The initial task for the laboratory trial was to obtain samples of the proposed fillcrete mix constituents, i.e. Portland Cement, Classified Flyash, fine aggregate and admixtures. The aggregate samples were screened on a 10 mm sieve to remove any oversized aggregate. The screened aggregate samples were tested to determine grain size distribution, specific gravity, absorption and organic content.

6.1 Cementing Materials

The majority of the fillcrete produced in the Edmonton area is made using Type 10 (Normal) Portland Cement manufactured at Inland Cement Limited's Edmonton plant. Mill certificates for the Type 10 Cement manufactured at this plant indicate that it complies with CSA-CAN3-A5-M83. Cement used for the trial mixes was obtained from Inland Cement Limited in 40 kg bags.

The classified flyash used for the trial mixes was produced at the Sundance Power Plant by Western Canada Flyash. Mill certificates for the classified flyash produced at this source indicate that it is a Type F flyash complying with CSA-A23.5-M86 and ASTM-C618. The flyash was obtained in 40 kg bags. No attempt was made to obtain mill certificates for the lots represented by the bagged products.

The Type 'N' slaked lime was produced by Continental Lime Ltd., and was obtained in 40 kg bags.

6.2 Aggregates

The first phase of the laboratory trials was conducted using fillcrete produced with a fine concrete aggregate (FCA). The FCA (Sample 3036) used for the laboratory trials was obtained from a local ready-mix concrete producer. The grain size analysis of Sample 3036 is presented as Figure 4. The aggregate grading is slightly finer than CAN/CSA-A23.1-M90 specifications on the 0.630 mm sieve, but is typical of the material currently used to produce fillcrete.

Samples of elimination sand were obtained from Consolidated Concrete Limited's General Pit near Villeneuve (Sample 3045) and TBG Contracting Ltd's Pit #21 (Serna Pit) south of Fort Saskatchewan (Sample 3067). The samples were obtained from existing 1989 stockpiles using loaders provided by the aggregate producers.

The grain size analysis of the elimination sand from the General Pit (Sample 3045.1) is presented as Figure 5. The sample grading is somewhat finer than average grading of the 1989 stockpile as supplied by the aggregate producer. The theoretical grading of the sand after screening on the 10 mm sieve (Sample 3045.2) is presented as Figure 6. The major differences between the elimination sand from the General Pit (ESG) and the FCA sample are the increased amount of material retained on the 2.5 and 5 mm sieves and the increase in fines (material passing the 0.080 mm sieve) content. Note that processing of the fine concrete aggregate included washing to remove excess fines.

The grain size analysis of the elimination sand from the Serna Pit (Sample 3067.1) is presented as Figure 7. The sample grading is considerably finer than average grading of the 1989 stockpile as supplied by the aggregate producer, having only 2.6 percent material retained on the 1.25 mm sieve. The elimination sand from the Serna Pit (ESS) is a uniformly graded sand with a higher fines content and a significantly finer grading than the fine concrete aggregate sample.

The grain size analysis of the bottom ash from the Wabamun Power Plant (Sample 3019) is presented as Figure 8. The gradings of samples of bottom ash after screening on the 10 mm sieve, Samples 3019.2 and 3063.1, are presented as Figure 9 and 10, respectively. The screened bottom ash from Wabamun (BAW) is less uniformly graded than the CSA-A23.1 fine concrete aggregate grading specifications, having somewhat more coarse sand, fine sand and fines.

The fine aggregate samples were also tested to determine relative density, absorption and organic content. Aggregate test results are summarized in Table 5.

Table 5

Aggregate Properties

Material	FCA	ESG	ESS	BAW
Bulk Relative Density	2.59	2.53	2.52	1.90
Bulk Relative Density (SSD)	2.63	2.59	2.58	1.98
Apparent Relative Density	2.69	2.68	2.68	2.07
Absorption	1.4%	2.2%	2.3%	4.3%
Fineness Modulus (FM)	2.28	2.37	1.53	2.69
Colour Plate	3	3	3	5

6.3 Admixtures

The air entraining admixture used was a neutralized vinsol resin type complying with CAN3-A266.1-M78 or ASTM C-260. The air entraining admixture dosage rates were in accordance with the manufacturer's recommendations. Dosage rates were varied as required to obtain the design air content.

The water reducing admixture used was an aqueous solution of metallic salts of lignin sulfonic acids complying with CAN3-A266.2-M78 Type WN or ASTM C-494 Type A specifications for a normal setting water reducer. The water reducing admixture dosage rate was slightly higher than the mean dosage rate recommended by the manufacturer. The dosage rate was raised slightly in an attempt to ensure the small amounts of cementing materials were thoroughly dispersed in the fillcrete mixture.

Admixture dosage rates are usually based on cementing materials content, because the cementing materials normally

constitute the majority of the fines in a mix. Compared to conventional concrete, the higher aggregate fines content of the fillcrete mixes requires a slight increase in dosage rate to compensate for the increased amount of fines in addition to the cementing materials.

7.0 LABORATORY TRIALS

A series of fillcrete mix designs were produced using concrete fine aggregate and a standard cementing materials content. These mixes were used to determine the influence of slump, air entraining admixture and water reducing admixture on the workability and compressive strength of the fillcrete mix. Based on these mix designs, it was concluded that an air entrained fillcrete mix produced with a water reducing admixture provided the most workable material. Mix designs were then produced to evaluate the affect of changing the relative proportions of Portland Cement and classified flyash. Fillcrete mixes were produced using the alternate fine aggregates identified in Phase I of this study: Elimination sands from the General and Serna Pits and bottom ash from the Wabamun Power Plant. Two mix designs were produced to confirm initial indications that slaked lime and classified flyash were not suitable for use as alternate cementing materials for fillcrete production.

7.1 Trial Mixes

A total of twenty five fillcrete mixes were produced for the laboratory trials. The batched mix proportions, including admixtures used, are presented in Table 6. This table also summarizes the slump, air content, plastic yield, consolidation, water/cement (W/C) and water/cementing materials (W/CM) ratios of the mixes. The fillcrete mixes were produced in EBA's Edmonton laboratory using a 0.085 m^3 rotary drum mixer. The batching sequence started with charging the mixer with approximately 80 percent of the design mix water, cement and flyash. Admixtures, if any, were diluted with water and added separately to the mixer. After the water and cementing materials were thoroughly blended, which usually took from 30 to 60 seconds, the aggregate was added to the mixer. Final tempering of the mix was done after 1 to 3 minutes of mixing.

The fresh fillcrete was tested to determine slump and air content. Because of the unstable nature of some of the

TABLE 6

Fillcrete Mix Designs

Mix	Batched Mix Proportions (kg/m3)					Air Entraining	Water Reducing	Slump	Air Content	Yield	Consolidation	Water/ Cement	Water/ CM
Number	Cement	Flyash	Aggregate	Water	Total	Admixture	Admixture	(mm)	(%)	(m3)	(%)	Ratio	Ratio
FCA1	40	60	1700	336	2136	No	No	90	2.8	1.055	2.3	8.40	3.36
FCA2	40	60	1660	315	2075	No	No	85	2.8	1.017	2.6	7.88	3.15
FCA3	40	60	1610	327	2037	No	No	140	1.0	0.992	3.5	8.18	3.27
FCA4	40	60	1545	330	1975	No	No	190	1.7	0.977	4.8	8.25	3.30
FCA5	40	60	1660	305	2065	Yes	No	45	4.5	1.036	2.3	7.63	3.05
FCA6	40	60	1624	290	2014	Yes	No	65	6.4	1.015	3.5	7.25	2.90
FCA7	40	60	1578	327	2005	Yes	No	105	4.1	1.011	2.1	8.18	3.27
FCA8	40	60	1571	310	1981	Yes	No	120	4.1	0.991	3.2	7.75	3.10
FCA9	40	60	1505	335	1940	Yes	No	200	5.1	1.001	3.3	8.38	3.35
FCA10	40	60	1627	287	2014	Yes	Yes	65	7.2	1.022	2.0	7.18	2.87
FCA11	40	60	1579	312	1991	Yes	Yes	130	4.5	0.990	5.0	7.80	3.12
FCA12	40	60	1597	274	1971	Yes	Yes	90	5.4	0.976	2.4	6.85	2.74
FCA13	30	70	1645	280	2025	Yes	Yes	80	7.2	1.024	4.1	9.33	2.80
FCA14	50	50	1655	280	2035	Yes	Yes	75	7.8	1.030	1.0	5.60	2.80
FCA15	40	60	1650	280	2030	Yes	Yes	95	6.3	1.014	3.0	7.00	2.80
ESG1	40	60	1599	278	1977	Yes	Yes	110	4.5	0.982	2.0	6.95	2.78
ESG2	40	60	1625	280	2005	Yes	Yes	85	5.4	1.004	1.0	7.00	2.80
ESS1	40	60	1619	302	2021	Yes	Yes	100	5.0	1.023	0.7	7.55	3.02
ESS2	40	60	1554	305	1959	Yes	Yes	120	5.5	1.005	-	7.63	3.05
BAW1	40	60	777	491	1368	Yes	Yes	210	1.3	0.938	2.5	12.28	4.91
BAW2	40	60	816	452	1368	Yes	Yes	190	1.6	0.922	4.0	11.30	4.52
BAW3	40	60	905	450	1455	Yes	Yes	55	5.5	1.005	2.4	11.25	4.50
BAW4	40	60	876	465	1441	Yes	Yes	90	3.8	0.988	3.8	11.63	4.65
LF1	15	85	1609	282	1991	Yes	Yes	90	4.2	0.983	4.1	N/A	2.82
LF2	20	110	1571	265	1966	Yes	Yes	180	3.9	0.963	1.0	N/A	2.04

FCA = Fine Concrete Aggregate | ESS = Elimination Sand, Serna Pit | LF = Lime Flyash
ESG = Elimination Sand, General Pit | BAW = Bottom Ash, Wabamun Power Plant | CM = Cementing Materials

mixes, the standard slump test was not always found to be an appropriate measure of mix workability. Some mixes bled water so rapidly that a mix with a flowable appearance in the mixer would have a relatively low slump in a slump cone. The workability of the mix was visually assessed by pouring the mix into a wheelbarrow. While in the wheelbarrow, the sensitivity of the mix to vibration was determined using a small pencil vibrator.

A K-slump tester was used in an attempt to provide a more reliable measurement of mix workability. This instrument works by measuring the amount of mortar (water, cementing materials and fine aggregate) in a mix that will flow through perforations in a 20 mm diameter tube. As the workability of a mix increases, the amount of mortar flowing into the tube tends to increase, increasing the K-slump value. With most fillcrete mixes, bleed water completely filled the tube. Consequently, the K-slump values could not be correlated to the visual appearance and/or slumps of the mixes.

7.2 Consolidation

Fillcrete mixes tend to consolidate (decrease in volume) in the initial 24 hours after placement. This consolidation is generally attributed to loss of bleed water and densification of the aggregate rather than drying shrinkage. Consolidation of the fillcrete mixes was determined by measuring the change in height of fillcrete placed in an undrained 152.4 mm diameter cylinder mold. When the fresh fillcrete was placed in the mold, care was taken to avoid overfilling the mold and losing any bleed water. The percentage consolidation was calculated based on the original height of fresh grout in the mold. The consolidation values for the fillcrete mixes are presented with the mix designs in Table 6.

7.3 Compressive Strength Testing

The fillcrete samples used for compressive strength testing were cast in accordance with CSA A23.2-3C. Cylinders were

formed using disposable cardboard cylinder molds. The samples were allowed to field cure for 48 hours at room temperature before they were transferred to a water bath for moist curing. To minimize possible sample disturbance, the cardboard molds were not removed until immediately prior to testing for compressive strength.

Compressive strength testing was done in accordance with A23.2.9C, with the following exception of cylinder capping. At early ages, it was not always possible to cap the fillcrete cylinders with sulphur mortar. The relatively weak fillcrete cylinders tended to break when removed from the capping jig. To minimize sample disturbance, rather than using sulphur mortar, compressible acoustic tile was used to provide a stress distribution at the sample ends. This technique was used for all compressive strength testing.

The compressive strength of the fillcrete mixes was tested at ages of 24-hours, 2, 7, 28, and 56-days. Some mixes were also tested at ages of 91 and 156-days. At 24-hours, 304.8 x 152.4 mm diameter cylinders were tested to determine the drained and undrained compressive strengths. The 2, 7, 28, 56 and 91-day undrained compressive strengths were determined using duplicate 203 x 108 mm diameter cylinders. To compare the effect of cylinder diameter on compressive strength, the 7-day undrained compressive strength was also determined using duplicate 152.4 mm diameter cylinders. Compressive strength results are summarized in Table 7.

Compressive strength at 24 and 48-hours was also measured by obtaining pocket penetrometer readings on drained and undrained samples. Pocket penetrometer readings are summarized in Table 8.

7.3.1 Effect of Cylinder Size

Unpublished data from the City of Edmonton indicated that, for fillcrete tested during 1989, there was no significant difference in a 28-day compressive strength

TABLE 7

Fillcrete Compressive Strength (kPa)

Age (days)	1D	1U	2	7	7	28	56	91	152	180
Mix Number	Cylinder Diameter (mm)									
	152.4	152.4	108	152.4	108	108	108	108	108	108
FCA1	17	U/S	25	100	82	345	N/S	866	N/T	N/T
FCA2	13	12	23	110	80	442	685	926	N/T	N/T
FCA3	20	14	N/T	135	117	481	724	N/T	N/T	N/T
FCA4	22	24	47	101	114	418	737	761	945	N/T
FCA5	59	73	N/T	161	146	511	873	986	N/T	N/T
FCA6	44	33	51	156	151	510	850	913	1090	1195
FCA7	N/T	N/T	N/T	113	129	667	964	1112	1305	N/T
FCA8	29	33	43	104	156	468	746	751	1085	N/T
FCA9	N/T	N/T	N/T	111	105	529	862	867	940	N/T
FCA10	53	61	66	166	202	532	830	824	N/T	N/T
FCA11	32	24	49	139	49	456	741	928	1140	N/T
FCA12	63	36	68	170	131	405	915	1185	1175	N/T
FCA13	29	29	33	73	77	394	403	1235	1340	N/T
FCA14	46	28	129	269	219	636	976	1455	1625	N/T
FCA15	37	43	N/S	N/T	185	499	767	N/T	N/T	N/T
ESG1	176	112	161	313	305	664	905	1320	N/T	N/T
ESG2	124	122	165	300	231	528	748	1115	1660	1195
ESS1	N/S	100	131	N/S	222	388	633	818	829	957
ESS2	105	92	117	184	182	498	751	1110	1210	1185
BAW1	29	N/S	31	52	49	151	146	N/T	N/T	N/T
BAW2	48	19	34	72	102	246	N/T	N/T	N/T	N/T
BAW3	39	12	51	68	68	167	177	N/T	N/T	N/T
BAW4	34	19	51	94	N/T	N/T	N/T	N/T	N/T	N/T
LF1	N/S	N/S	N/S	N/S	N/S	N/S	N/T	N/T	N/T	N/T
LF2	N/S	N/S	N/S	N/S	N/S	N/S	N/T	N/T	N/T	N/T

1D = Drained Mold   N/T = Not Tested
1U = Undrained Mold   N/S = Not Stripable, broken or too soft to strip mold

TABLE 8

Pocket Penetrometer Test Results
Unconfined Compressive Strength (kPa)

Mix Number No.	D 1-day	D 2-day	U 1-day	U 2-day
FCA1				
FCA2				
FCA3	124		110	
FCA4	150	230+	104	196
FCA5	92		83	
FCA6	92	230+	127	230+
FCA7	230+	230+	230+	230+
FCA8	127	207	115	207
FCA9	230+	230+	230+	230+
FCA10	161	230+	150	219
FCA11	104	173	104	173
FCA12	230+	230+	207	230+
FCA13	196	184	115	219
FCA14	115	230+	138	184
FCA15	115	230+	127	184
ESG1	230+	230+	230+	230+
ESG2	230+	230+	230+	230+
BAW1	161	207	150	207
BAW2	196	230+	138	207
BAW3	127	230+	150	230+
BAW4	173		184	
LF1	12	23	12	23
LF2	12	35	12	12

D = Drained Mold
U = Undrained Mold
Compressive Strength equal to q /2

between 108 mm and 152.4 mm diameter cylinders. Based on this data, the decision was made to use the smaller sized cylinders to provide an increased number of samples. To verify this assumption, the 7-day compressive strength was determined for both sizes of cylinders (see Table 7). Test results are presented graphically in Figure 14. The dotted line indicates equal compressive strength for the two sizes of cylinders. The solid line plots the linear regression for the test data, excluding the one obvious outlier. The linear regression of $y=24.72+0.79x$ has a correlation coefficient of $R=0.93$, confirming that there is a definite linear relationship between the 7-day compressive strength for the two cylinder sizes. However, the smaller cylinders did tend to have slightly lower compressive strengths. Because all mixes were tested using the same size cylinders, it was concluded that this variation had no significant impact on the relative performance of the fillcrete mixes.

7.3.2 Drained Cylinder Molds

Conventional concrete cylinders are formed in undrained cylinder molds. It is assumed that concrete does not lose a significant amount of mix water due to internal drainage or bleeding. Fillcrete mixes, especially non-air entrained mixes, can contain a significant amount of excess mix water (i.e. mix water which will drain and/or bleed out of the mix shortly after the mix is placed). To model the effect of drainage on the fillcrete compressive strength at early ages, comparison samples were cast using drained 152.4 mm diameter molds.

The drained molds were prepared by drilling a number of 3 mm diameter holes in the bottom of the cylinder mold. To model drainage in a utility trench, the perforated mold was placed in a 20 litre pail filled with loose sand. A comparison of the 24-hour drained and undrained compressive strength is presented in Figure 15.

The dotted line indicates equal 24-hour compressive strengths for the drained and undrained cylinders. The solid line plots the linear regression of $y=1.46+0.81x$ for the test data. The correlation coefficient of $R=0.91$ indicates that there is a definite correlation between drained and undrained 24-hour compressive strength, with the drained strength being approximately 20 percent higher.

Cementing of the sand under the drained mold was observed for the non-air entrained fillcrete mixes. This indicates that migration of cementing materials is more noticeable without air entrainment.

7.4 Freeze/Thaw Testing

Representative samples of fillcrete (mix FCA15) were subjected to 20 cycles of freezing and thawing after 28-days of standard moist curing.

Three sets of duplicate 108 mm diameter cylinders were subjected to differing curing conditions. After 28-days of moist curing, the cylinders were stripped of the cardboard molds. One pair of samples was moist cured for an additional 28 days to provide a control sample. The remaining two pairs of samples were subjected to 20 cycles of freezing and thawing. One pair of samples was sealed in polyethylene bags to prevent sample drying, while the other pair of samples was exposed to air at ambient temperature and humidity. The samples were stored in a freezer with an ambient temperature of approximately -15°C for a minimum period of 14 hours. During regular working hours, the fillcrete samples were removed from the freezer in the morning and allowed to warm to room temperature for a period of 8 to 10 hours. At the end of the day, the samples were returned to the freezer. Samples were kept frozen over weekends. All samples were tested for compressive strength at an age of 56-days. Test results are summarized in Table 9.

Table 9
Freeze/Thaw Test Results

	Compressive Strength (kPa)			
Curing Condition	CSA A23.2-3C	CSA A23.2-3C (Control)	Sealed In Bag (Freeze/Thaw)	Exposed to Air (Freeze/Thaw)
Age	28-day	56-day	56-day	56-day
	530	675	432	587
	467	859	515	602
Average	**499**	**767**	**474**	**595**

7.5 Bottom Ash Mixes

The performance of the fillcrete mixes will be discussed in detail in later sections of this report. One aspect of the performance of fillcrete mixes produced with bottom ash was observed during the production of the trial mixes. As shown in Table 10, the slump of the bottom ash mixes increased with mixing time, while the air content decreased. The changes in slump with mixing time are presented graphically in Figure 16.

Table 10
Bottom Ash Mix: Changes With Mixing Time

Mix	BAW4			BAW4A		
Mixing Time (mins)	Slump (mm)	Air Content (%)	Density (kg/m^3)	Slump (mm)	Air Content (%)	Density (kg/m^3)
10	5	6.0	1493	105	3.4	1523
20	40	4.7	1506	135	2.7	1530
30	90	3.8	1531	220	1.6	1554
40	140	3.2	1550	225	1.4	1567
50	215	2.7	1572	235	1.4	1590
60	215	1.8	1583			

The decrease in entrained air content is attributed to the organic content of the bottom ash. It is difficult to maintain a stable air content using an aggregate with a

significant coal and/or organic content.

The slump gain is attributed to the nature of the bottom ash particles. Bottom ash includes a significant proportion of porous, friable particles. The porous nature of bottom ash is evidenced by the high natural moisture contents of 30 to 35 percent. It is hypothesized that the increase in slump was due to the breakdown of bottom ash particles. As the particles abrade, the rough edges are removed, reducing internal friction in the mix. It is also possible that water entrapped in the porous particles is released into the mix as the particles break down.

To verify this hypothesis, samples of bottom ash and the fillcrete mix produced with this bottom ash (BAW4A) were analyzed for grain size distribution. (Mix BAW4A and BAW4 were identically proportioned, however no compressive strength samples were prepared for mix BAW4A). Samples were obtained prior to mixing and after mixing times of 10, 30 and 50 minutes. (Samples 3063.1, 3063.2, 3063.3 and 3063.4 respectively). The theoretical grain size distributions of the bottom ash, excluding the cement and fly ash, are presented in Table 11. These theoretical gradings are represented by the lower solid lines on Figures 11, 12 and 13.

Table 11
Bottom Ash Grain Size Distribution

	Percent Passing							
Sieve Size (mm)	10	5	2.5	1.25	0.630	0.315	0.160	0.080
Sample prior to mixing	100	91.9	80.8	69.3	56.8	38.1	17.9	7.5
Sample after mixing 10 minutes	100	91.1	79.8	68.6	57.0	39.6	19.6	7.7
Sample after mixing 30 minutes	100	91.8	81.3	70.3	59.3	42.3	21.9	8.5
Sample after mixing 50 minutes	100	90.9	80.0	69.7	59.9	44.4	24.2	11.0

The bottom ash gradings presented in Table 11 indicate that, as the mixing of the bottom ash fillcrete continues, the fine sand size bottom ash particles are being broken down, resulting in an increase in material passing the 0.315, 0.160 and 0.080 mm sieves. Unfortunately, this testing was not sufficient to determine how the observed particle breakdown resulted in the observed slump increase. The possible consequences of this phenomenon are discussed in later sections of this report.

8.0 OPTIMIZED FILLCRETE MIX DESIGNS

8.1 General

The laboratory trial program established that the use of air entraining and water reducing admixtures substantially improved the performance of the fillcrete mixes produced with fine concrete aggregate (FCA). Without the addition of admixtures, the fillcrete mix behaved like wet sand when discharged from the mixer. Subsequent trial mixes established that the alternative natural fine aggregates could be used to produce fillcrete of similar quality to that produced with FCA. The results of compressive strength testing have been presented in Tables 7 and 8.

The four trial mixes produced using screened bottom ash indicated that it should be possible to produce fillcrete utilizing this material. However, the potential for the use of bottom ash will require additional laboratory study, as well as field trials, to determine the effect of the minimal long term compressive strength gains, high stockpile moisture contents, particle durability, and slump gain on field performance.

The following sections summarize the findings of the laboratory study.

8.2 Admixtures

The initial four mixes were produced without admixtures (mixes FCA1, FCA2, FCA3 and FCA4). These mixes exhibited massive bleeding and loss of slump upon discharge from the mixer, as well as reduced compressive strengths (see Figure 17). These mixes behaved like wet sand, having virtually no ability to flow unless vibrated. The workability of a mix produced without air entraining and water reducing admixtures could be improved by the use of significantly increased amounts of a pozzolanic mineral admixture such as flyash, however this would add significantly to the cost of the mix and very

probably, increase the long term compressive strength gain.

In conventional concrete production, entrained air can be used to improve the workability of the mix while controlling the amount of bleeding. The addition of an air entraining admixture to the fillcrete mix (mixes FCA5, FCA6, FCA7, FCA8 and FCA9) reduced bleeding and produced a more workable mix, especially at lower slumps. At slumps of 100 to 120 mm, mix segregation was delayed to approximately 30 to 90 seconds after placement. At higher slumps (190 to 200 mm), massive bleeding and severe loss of slump upon discharge from the mixer were still noted. Shortly after discharge, the workability of the lower slump mixes generally appeared superior to that of the high slump mixes. The overall behaviour of the air-entrained mixes was still similar to that of wet sand.

The addition of entrained air tended to increase the compressive strength of the mixes (see Figure 18). Note that the variability of compressive strength between mixes also increased.

To investigate additional means of improving the workability and compressive strength of fillcrete, the use of a water reducing admixture was evaluated. The addition of a water reducing admixture (mixes FCA10, FCA11, and FCA12) significantly reduced the segregation and improved the workability of the fillcrete, producing a mix with a plastic consistency similar to that of conventional concrete. The use of a water reducing admixture also tended to reduce setting time and increase compressive strength at early ages (see Figure 19).

The rapid segregation and slump loss of the mixes produced without admixtures makes these mixes difficult to place and consolidate without vibration. The use of water reducing and air entraining admixtures significantly improved the workability of the fillcrete mixes, while providing a slight increase in compressive strength.

8.3 Cement Content

To briefly examine the effect of changing the proportions of cement and flyash, three mixes were produced using the standard cementing materials content of 100 kg/m^3 (mixes FCA12, FCA13, and FCA14). Mix FCA12 was a control mix with a cement content of 40 kg/m^3 and a flyash content of 60 kg/m^3. Mix FCA13 was produced with a reduced cement content of 30 kg/m^3. Compared to mix FCA12, this mix had reduced compressive strength at early ages, with slightly higher compressive strength at later ages (see Figure 20). This pattern of strength gain is not considered suitable for fillcrete. Lower strengths at early ages will tend to slow subsequent construction, while increased long term strength will tend to reduce future excavatability.

Mix CFA14 was produced with a cement content of 50 kg/m^3. It exhibited increased compressive strength at all ages (see Figure 20).

It is anticipated that individual fillcrete producers will wish to make minor changes in the cementing materials content. Based on this testing, major changes appear unlikely.

8.4 Natural Aggregates

The majority of the laboratory trials were conducted using fillcrete produced with natural fine aggregates. These included a typical washed fine concrete aggregate (FCA) and elimination sands from the General Pit near Villenueve (ESG) and the Serna Pit south of Fort Saskatchewan (ESS). The two elimination sands selected respectively represent typical coarse and fine extremes for elimination sands in the Edmonton area. The ESG can be processed to satisfy the CSA grading requirements for fine concrete aggregate by screening/crushing and washing. The ESS is a uniformly graded fine sand with a significantly finer grading than the CSA grading requirements as well as a higher fines content.

The results of the laboratory test program indicate that, when produced at similar slump and air contents, there was no significant difference in the compressive strengths of the mixes produced with the three different natural aggregates (See Figures 21, 22 and 23). There appears to be an advantage in using the unwashed elimination sands as the workability of the fillcrete mix tended to increase with the amount of fines in the aggregate. A reduced tendency towards mix segregation was noted for the unwashed aggregates, especially with the ESS mixes.

8.5 Bottom Ash

In a recently completed study by Dilger and Goodrich, it was confirmed that the depth of frost penetration in fillcrete is significantly higher than the depth of frost penetration in compacted high plastic clay backfill, and somewhat higher than in compacted sand backfill. To investigate the potential for producing a fillcrete mix with a decreased thermal conductivity (thus reducing the depth of frost penetration), mixes were produced using bottom ash, a low density waste product of coal fired generating stations. Bottom ash from the Wabamun power plant (BAW) was used for the study.

The BAW mixes displayed some unique properties. After initial mixing, they had similar workability to the natural aggregate mixes. However, as mixing continued, the slump of the mix increased dramatically with a loss of entrained air content. The loss of entrained air content is attributed to the high carbon content of the bottom ash. The increase in slump is attributed to the degradation of the friable bottom ash particles. Further investigation of this particle degradation will be required to determine its influence on field production.

It was noted that the tendency of the BAW mixes to segregate at slumps in excess of 100 to 150 mm was significantly reduced from that of the natural aggregates (i.e. CFA, ESS and ESG). This is attributed to the higher fines content of the bottom

ash. The lower density of the bottom ash particles may also tend to reduce the rate of segregation. The setting time of BAW mixes was slightly slower than usual. The 1 and 2 day compressive strengths were at the low end of the normal range. At ages in excess of 2 days, the BAW mixes had significantly lower compressive strengths and strength gains (see figure 24). It was also noted that the strength of the BAW mixes peaked after only 28 days, far earlier than the natural aggregate mixes. This is attributed to the weak, friable nature of the bottom ash particles.

The objective of the laboratory trials of the BAW mixes was to determine if further investigation of these mixes was warranted. The results of the laboratory trials indicate that it should be possible to produce fillcrete mix with improved excavatability and reduced thermal conductivity using bottom ash. An increased cementing materials content may be required to improve the initial setting time and early compressive strength of a bottom ash mix. The long term strength gain of the bottom ash mixes was much lower than that of the mixes produced with natural aggregates. Consequently, a bottom ash mix can be placed with a higher early strength without compromising long term excavatability. The results of the initial laboratory trails indicate that a more detailed study should be made into the potential for producing fillcrete with bottom ash.

Lovell et al, in a series of tests on bottom ashes from various Indiana sources, concluded that, except for corrosiveness, untreated bottom ash can be used extensively for highway construction. The corrosiveness of the bottom ash was variable, and it was recommended that "bottom ashes having high corrosiveness should not be placed in the near vicinity of any metal structure." Further study is required to determine the corrosiveness of the local bottom ashes, and if this will impact on their suitability for use in fillcrete.

8.6 Excavatability

The long term excavatability of selected fillcrete mixes was assessed by hand augering using a brace and bit.

Some of the samples used for pocket penetrometer testing were retained for testing at an age of 6 months. After 24 hours of curing, in accordance with CSA-A23.2-3C, the samples were sealed in polyethylene bags and stored at room temperature until testing. A relative measure of excavatability was obtained using a 25 mm carbide tipped drill bit. The bottom ash mix samples could be easily penetrated with moderate pressure. The samples of the natural aggregate mixes (i.e. FCA, ESS and ESG) required firm to relatively heavy pressure on the bit.

The hand augering test procedure appears promising for evaluating the excavatability of fillcrete. To provide more accurate results, it would be necessary to correlate actual field excavatability to the ease of drilling with a brace and bit.

This preliminary testing indicates that it should be possible to excavate the fillcrete mixes tested using conventional trench excavation equipment (i.e. tractor backhoe/loader, ditchwitch, etc.). The literature review indicated that the long term compressive strength of fillcrete should be limited to 2000 kPa to ensure relative ease of excavation. The 1100 to 1300 kPa compressive strength of the fillcrete mixes tested appears to be close to maximum compressive strength tolerable for excavatability. An interim guideline of maximum compressive strength 1500 kPa is recommended until detailed field trials can be evaluated. The maximum 28-day compressive strength of 600 kPa currently specified by the City of Edmonton is consistent with achieving this guideline.

8.7 Optimized Fillcrete Mix Designs

Based on the results of the laboratory testing program, the optimized fillcrete mix designs are presented as Table 12. Individual fillcrete producers may wish to conduct additional investigation into fine tuning mix proportioning for their particular fillcrete aggregate.

TABLE 12

Optimized Fillcrete Mix Designs

Material (kg/m^3)	FCA	ESS	ESG	BAW
Water	280	302	280	465
Type 10 Portland Cement	40	40	40	40
Classified Flyash	60	60	60	60
Fine Concrete Aggregate	1680			
Elimination Sand, Serna Pit		1590		
Elimination Sand, General Pit			1650	
Bottom Ash				900
Yield, kg/m^3	2060	1992	2030	1465

Note: All aggregates proportioned saturated surface dry (SSD).

Optimized Mix Properties

Slump, 100 mm $\pm$ 25 mm

Air Content (minimum), 4%

Maximum Setting Time, 2 Days

Maximum 28-Day Compressive Strength, 600 kPa

Maximum Long-Term Compressive Strength, 1500 kPa

Notes: The usefulness of air entraining bottom ash mixes should be confirmed by further laboratory and field trials.

Slump shall be limited to avoid excess bleeding and segregation of the mix.

9.0 COST ANALYSIS

9.1 Cost of Typical Residential Utility Works

The total cost of residential utility works includes the installation cost, maintenance and repair costs, and intangible costs such as the disruption caused during construction. A complete economic analysis of various construction alternatives should address all of these costs.

Installation costs include the costs of excavation, disposal of excavated material, pipe, pipe bedding, pipe laying, and backfilling. In any given installation, one of these operations may govern the overall production rate attainable, thereby affecting the cost of the other operations and the total installation.

In new construction, the rate of pipelaying and backfilling can be the controlling factor governing the rate of production. In urban renewals, the excavation rate is often the controlling factor, as it may be slowed significantly by the presence of existing utilities and confined operating conditions.

Excavation costs are dependent on the production rate attained with the equipment being used. The production rate attained is determined by site accessibility, the size of the excavation equipment used, the type of material excavated, the depth of the trench, the bottom width of the trench (determined by number and size of pipes installed) and the trench configuration (i.e. either vertical cut or vee-cut).

The trench configuration used may be determined by the type of material being excavated or by the proximity of existing developments. Although the volume of material excavated is less when vertical cut trenches are used, there will be additional costs due to shoring requirements. The lower cost vee-cut trenches are used for the majority of new construction projects. In urban renewal situations, vertical cut trenches

are often used to minimize disturbance to existing adjacent development.

In installations where the excavated material is suitable for re-use as backfill, there will be no disposal costs. If the excavated material is unsuitable for re-use as backfill, disposal costs may be minimized by on-site disposal. Generally this is only feasible in new construction. On renewal projects, disposal costs are dependent on the haul distance to the disposal site.

Pipe, pipe bedding and pipe laying costs are primarily dependent on the type, size and number of pipes and service connections, and on the type of bedding used. The production rate achieved by a pipe laying crew may be limited by the excavation rate. If the excavation rate does not equal or exceed the capacity of the pipe laying operation, the cost of pipe laying will increase. Similarly, if the excavation capacity greatly exceeds the pipe laying capacity, the excavation costs will increase. A balance between excavation rate and pipe laying rate is not always possible, as each may vary considerably during the course of the project.

The costs of backfilling include the backfill material supply and hauling costs, and placing costs. Typical backfill materials used include native material, imported clay, imported sand, and fillcrete. If native material from the trench excavation is used as backfill, there are no supply or hauling costs. The supply and hauling costs of the other alternatives will depend on location and haul distances. Generally, imported clay will be less expensive than imported sand, while fillcrete will be considerably more expensive than compacted backfill. Placing costs include handling and compaction. They are lowest with fillcrete and highest with clay backfill. The differences in placing costs are due to equipment requirements and production rates achievable. Although they are minimized with fillcrete, backfill placing costs typically play a minor role in the overall installation cost.

The type of backfill used in a typical residential utility work installation will have an effect on future maintenance and repair costs. Excavation costs will generally be lower if sand backfill was used in the initial installation. However, in cases where the sand has become saturated, there may be considerable trench wall sloughing, thus shoring may be required. To date, there has been limited experience with maintenance on trenches initially backfilled with controlled strength fillcrete. If the fillcrete was properly designed, the potential for increased trench wall stability may more than offset any increased excavation costs.

In summary, fillcrete has no effect on the initial excavation and pipe-laying costs. The factors affecting these operations are determined by soil conditions and site constraints. Fillcrete does, however, have a significant effect on the costs of the backfilling operation and a potentially significant effect on maintenance costs. In comparison to native backfill, the additional costs involved using fillcrete include the high cost of the supply and delivery of the fillcrete, and the disposal costs of the excavated material. The savings realized include decreased placing costs and time spent on the backfilling operation. In comparison to either imported clay or sand backfill, the additional costs involved with using fillcrete are limited to the price differential between fillcrete and the imported material. Again, the savings realized include decreased placing costs and time spent on the backfilling operation.

For new construction, fillcrete is not seen as a practical backfill alternate. Trench configurations in areas of new construction are generally determined solely by ground conditions and are usually vee-cut, due to the cost of shoring vertical trenches. In a vee-cut trench, the required volume of backfill material makes fillcrete an excessively costly alternative.

In renewal works, vertical cut shored trenches are typical, due to site constraints. The excavated material is often

unsuitable for re-use, due to excessive moisture and/or contamination with topsoil or other deleterious materials. In these situations, fillcrete may be a viable alternative to other imported materials. In a typical renewal installation consisting of a 250 mm diameter pipe in a vertical cut, 2 to 3 m deep trench, backfilling with fillcrete would cost approximately $75 to $100 more per lineal metre of trench than would backfilling with clay.

9.2 Cost of Optimized Fillcrete Design

The laboratory trial program determined that optimized fillcrete will have cementing materials and admixture costs very similar to that of the currently utilized mixes. Generic specifications for the production of the optimized fillcrete mix are presented in Appendix B. Using the cost analysis presented in Section 2.0, the July 1990 materials costs for a typical fillcrete mix, as currently produced with fine concrete aggregate, are presented in Table 13.

Table 13
Fillcrete Materials Costs

Material	Cost	Mix Design Quantity (per m^3)	Estimated Cost (per m^3)
Fine Concrete Aggregate	$8.00 - 8.75/tonne	1720 kg	$13.76 - 15.05
Portland Cement	$140/tonne	40 kg	$5.60
Classified Flyash	$40/tonne	60 kg	$2.40
Water	$1/tonne	230 kg	$0.23
Air Entraining Admixture	$1.10/litre	50 ml	$0.06
Water Reducing Admixture	$0.75/litre	500 ml	$0.38
Total Materials Cost			$22.43 - 23.72

The City of Edmonton's 1990 contract for fillcrete supply and delivery has a base price of $32.28/m³. This excludes any surcharges for items such as winter heat or unscheduled delivery. Subtracting the estimated materials cost of $22.43 to 23.72/m³ for the typical fillcrete mix leaves an average of only $9.20/m³ for the producer's production, delivery and profit.

The material costs represent three quarters of the price of fillcrete. The cost of the fine concrete aggregate represents over half of the materials cost of fillcrete mixes as currently produced.

The July, 1990 aggregate costs for the optimized fillcrete designs presented in Table 12 are summarized in Table 14. The aggregate quantities presented in this table have been adjusted to account for the difference between the Saturated Surface Dry (SSD) batch quantities presented in Table 12 and the average stockpile moisture content.

Table 14
Estimated Fillcrete Aggregate Costs

Aggregate	Cost (per tonne)	Mix Design Quantity (tonne/m³)	Estimated Cost (per m³)
Fine Concrete Aggregate	$8.00 - 8.75	1.72	$13.76 - 15.05
Elimination Sand	$5.50 - 6.50	1.64 - 1.70	$9.02 - 11.05
Bottom Ash	$11.80	1.14	$13.45

The laboratory trial program determined that the cost of fillcrete aggregate can be reduced by 20 to 40 percent by substituting elimination sand for fine concrete aggregate. This represents a potential cost saving of $2.71 to $6.03 per cubic metre of fillcrete. The actual reduction in the retail price of fillcrete will be influenced by marketing considerations.

The use of bottom ash instead of fine concrete aggregate results in a materials cost saving of approximately \$0.31 to \$0.60 per cubic metre. This cost saving is not sufficient in itself to justify the use of bottom ash in fillcrete. However, given that bottom ash will provide improved excavatability and reduced frost penetration, the overall prospects for this material appear favourable.

The alternate aggregates tested tended to improve the workability of the fillcrete, thereby making placement easier. This is unlikely to have any significant effect on the cost of using fillcrete.

Given the relatively high cost of fillcrete compared to conventional sand or clay backfill, the estimated material cost savings of \$2.71 to \$6.03 per cubic metre is unlikely to have a major impact on the economics of using fillcrete. The decision to use fillcrete is based primarily on factors such as speed and ease of placement, and assured performance. The use of a lower cost aggregate should, however, result in a lower cost to the consumer. If the cost of fillcrete had been reduced by \$3.00/m^3 during 1989 and 1990, the City of Edmonton would have saved \$219,000. (See Table 15).

Table 15
Potential Savings

Year	Amount of Fillcrete Placed	Base Price*	Total (\$1000)	Potential Savings (\$1000)
1989	35,151 m^3	\$32.78/m^3	\$1,152	\$105
1990	38,007 m^3	\$32.28/m^3	\$1,227	\$114
Total	**73,158 m^3**		**\$2,379**	**\$219**

* The base price excludes surcharges for items such as winter heat and unscheduled deliveries.

10.0 CONCLUSIONS AND RECOMMENDATION

10.1 Performance Criteria

The currently utilized cementing materials content of approximately 40 kg/m^3 of Portland Cement and 60 kg/m^3 of Classified Flyash provides a near optimal cementing materials content. No large variation from these quantities is recommended. The use of alternative cementing materials is not feasible.

The workability of a fillcrete mix is optimized when it is produced with a plastic consistency, i.e. with a slump of 100 $\pm$ 25 mm. The addition of extra water to obtain a higher slump mix with a flowable consistency was found to be detrimental to the workability of the mix due to the rapid rate of segregation.

The use of relatively low levels of air entrainment improves the workability of fillcrete. A minimum air content of four percent was sufficient to reduce the rate of mix segregation. Migration of cementing materials due to bleeding was significantly reduced with air entrainment and a minor increase in compressive strength was observed.

The use of a water reducing admixture is recommended in an optimized fillcrete mix. It substantially enhances the workability of fillcrete, while providing some improvement in compressive strength and setting time.

The admixture dosage rates for an optimized fillcrete mix will be approximately 10 to 20 percent higher than used for conventional concrete mixes.

The nominal maximum size of fillcrete aggregate should be limited to 10 mm. This will allow any inclusion of waste concrete to be easily identified.

Acceptable fillcrete can be produced with aggregate unsuitable for use in conventional concrete mixes. By utilizing the

locally available, lower quality aggregate instead of fine concrete aggregate, a cost savings of $2.71 to $6.03 per cubic metre can be realized. This has the added advantage of using elimination sand which frequently does not have commercial uses.

Preliminary trials indicate that bottom ash can be used to produce fillcrete with virtually no long term strength gain and greatly improved resistance to frost penetration.

10.2 Quality Control

The strict grading requirements for fine concrete aggregate contained in CAN/CSA A23.1-M90 are unnecessarily restrictive for fillcrete aggregate. Recommended fillcrete aggregate grading limits are presented in Item 2.1.3 of the Generic Fillcrete Specification contained in Appendix B. These relatively open grading limits do not necessarily exclude excessively clayey, uniform or gap-graded aggregates, and trial mixes are essential to ensure that the grading of a proposed aggregate produces a fillcrete mix of adequate workability, while minimizing segregation during and immediately after placement.

Conventional compressive strength testing in accordance with CSA A23.1-9C or ASTM C39 is not necessarily appropriate for CLSM's such as fillcrete. The extremely low strength of this material made it difficult to use conventional sulphur capping compound.

The results of the compressive strength testing indicate that fillcrete samples are inherently more variable than most conventional concrete products. A minimum of two samples should be tested at each specified age. The scope of the laboratory trial program was insufficient to determine whether anomalies such as encountered with mix ESG2 indicate too low a measured strength at 180 days or too high a strength at 152 days.

Test results also indicated that the size of the test cylinder has a significant impact on the compressive strength. The larger size (152 x 304 mm) cylinders tended to have 20 percent higher 7-day compressive strengths than 108 mm diameter cylinders, but were also much more likely to be damaged during curing and demolding. The smaller size test cylinder is considered preferable in terms of ease of handling and storage.

For the plastic consistency required to obtain the optimum fillcrete workability, the slump test (CSA A23.2-5C) provides an appropriate means of measuring fillcrete consistency.

The K-Slump tester did not provide a useful means of assessing fillcrete workability.

10.3 Future Study

Preliminary laboratory trials indicate that bottom ash can be used as a fillcrete aggregate. Further research into the physical, thermal, chemical and corrosion properties of this non-conventional aggregate is strongly recommended. Additional trials will be required to establish production techniques and address the concerns about the stability of mix slump and air content.

Additional study is required to better correlate the results of laboratory testing of fillcrete cylinders to field performance. Specifically, field trials are required to correlate compressive strength to excavatability. Hand augering with a brace and carbide tipped bit shows promise as an empirical measurement of excavatability.

Additional study is required to identify suitable materials for use in unbonded caps for compressive strength testing of fillcrete cylinders.

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GLOSSARY

ABSORBED MOISTURE - moisture that has entered a solid material by absorption and has physical properties not substantially different from ordinary water at the same temperature and pressure.

ABSORPTION - the process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body:also the increase in weight of a porous solid body resulting from the penetration of a liquid into its permeable pores.

ADMIXTURE - a material normally added in small amounts to concrete, mortar, or neat cement grout before or during mixing in order purposely to modify their usual characteristics and behaviour.

AGGREGATE - a natural, processed, or manufactured granular material having physical, chemical, and mineralogical characteristics suitable for use in mortar or concrete.

LOW-DENSITY AGGREGATE - aggregate of low relative density from which low-density structural concrete can be produced.

NORMAL-DENSITY AGGREGATE - natural sand, manufactured sand, gravel, crushed gravel, crushed stone, air-cooled iron blast-furnace slag, or any other suitable aggregate from which normal density concrete can be produced.

AIR-COOLED IRON BLAST-FURNACE SLAB - the material resulting from solidification of a molten nonmetallic product consisting essentially of silicates and aluminosilicates of calcium and other bases, developed simultaneously with iron in a blast-furnace.

AIR-ENTRAINED CONCRETE - concrete in which air in the form of minute bubbles has been occluded during the mixing period as a result of the use of an air entraining admixture.

AIR-ENTRAINING AGENT - an addition for hydraulic cement or an admixture for concrete or mortar which causes entrained air to be incorporated in the concrete or mortar during mixing, usually to increase its workability and frost resistance.

AIR-ENTRAINMENT - the occlusion of air in the form of minute bubbles (generally smaller than 1 mm) during the mixing of either concrete or mortar.

AIR-METER - a device for measuring the air content of concrete and mortar.

AIR VOID - a space in cement paste, mortar, or concrete filled with air; and entrapped air void is characteristically 1 mm or more in size and irregular in shape; an entrained air void is typically between 10μm and 1 mm in diameter and spherical or nearly so.

BLEEDING - the emergence of mixing water from plastic concrete or mortar.

CEMENT - Portland cement or blended hydraulic cement.

CEMENTING MATERIAL - Portland cement with or without a supplementary cementing material.

COLD JOINT - a joint or discontinuity formed when a concrete surface hardens before the next batch is placed against it.

CONCRETE - a composite material consisting essentially of a mixture of cementing material and water within which are embedded particles of fine and coarse aggregate.

> **FLOWING CONCRETE** - a homogeneous concrete having a slump greater than 180 mm.
>
> **NORMAL-DENSITY CONCRETE** - concrete having a fresh density between 2150 and 2500 kg/m^3 as determined by CSA Test Method A23.2-6C.
>
> **STRUCTURAL LOW-DENSITY CONCRETE** - concrete having a 28-day compressive strength in excess of 15 MPa and an air-dry density not exceeding 1850 kg/m^3 as determined by ASTM Standard C567.

STRUCTURAL SEMI-LOW DENSITY CONCRETE - concrete having a 28-day compressive strength in excess of 15 MPa and an air-dry density between 1850 and 2150 kg/m^3 as determined by ASTM Standard C567.

SUPERPLASTICIZED FLOWING CONCRETE - flowing concrete obtained by the use of a superplasticizing admixture.

CONSISTENCY - degree of fluidity of freshly mixed concrete or mortar.

FIELD CURED SPECIMENS - concrete test specimens cured as nearly as practicable in the same manner as the concrete in the structure.

FINENESS MODULUS - an empirical factor equal to 1% of the sum of the cumulative percentages by mass of a sample of aggregate retained on each of a specified series of sieves. The sieves used are adopted from CGSB Standard 8.2 as follows: 160 μm,315 μm,630 μm,1.25 mm,2.5 mm,5 mm, 10 mm, 20 mm, 40 mm, and 80 mm.

FLOATING - working the unformed surface of fresh concrete to produce a relatively even but still open texture.

FLYASH - The finely divided residue resulting from the combustion of ground or powdered coal and which is transported from the combustion chamber by suspension in the flue gases; known in UK as Pulverized Fuel Ash (pfa).

CLASSIFIED FLYASH - Flyash which has been processed using a cyclone classifier or similar means to remove larger sized particles, providing a product with less material retained on the 45 μm sieve, more uniform grain size distribution and reduced loss on ignition.

UNCLASSIFIED FLYASH - Flyash as collected from the flue gases.

HONEYCOMB - voids left in concrete due to failure of the mortar to fill effectively the spaces between coarse aggregate particles.

LAITANCE - a layer of weak material containing cement and fines from aggregates, brought by bleeding water to the top of the concrete.

MORTAR - a mixture consisting essentially of cementing material, fine aggregate, and water.

NOMINAL MAXIMUM SIZE OF COARSE AGGREGATE - the standard sieve opening immediately smaller than the smallest through which all of the aggregate must pass.

OWNER - the administrator of the requirements of this Standard or the designated representative, usually an engineer or an architect.

PLACING - the handling, deposition, and consolidation of freshly mixed concrete in the place where it is to harden.

PROPORTIONING - the selection of proportions of ingredients to produce concrete of the required properties.

SEGREGATION - the differential concentration of the components of mixed concrete, aggregate, or the like, resulting in non-uniform proportions in the mass.

SEPARATION - the tendency, as concrete is caused to pass from the unconfined ends of chutes or conveyor belts, or similar arrangements, for coarse aggregate to separate from the concrete and accumulate at one side:the tendency, as processed aggregate leaves the ends of conveyor belts, chutes, or similar devices with confining sides, for the larger aggregate to separate from the mass and accumulate at one side;or the tendency for the solids to separate from the water by gravitational settlement.

SET - the condition reached by a cement paste,mortar,or concrete when it has lost plasticity to an arbitrary degree, usually measured in terms of resistance to penetration or deformation; initial set refers to first stiffening; final set refers to attainment of significant rigidity; also, strain remaining after removal of stress.

> **FINAL SETTING TIME** - The time required for a freshly mixed cement paste, mortar or concrete to achieve final set.

INITIAL SETTING TIME - The time required for a freshly mixed cement paste, mortar or concrete to achieve initial set.

SUPPLEMENTARY CEMENTING MATERIAL - a material that, when used in conjunction with Portland cement, contributes to the properties of the hardened concrete through hydraulic or pozzolanic activity of both.

TOLERANCE - the difference between the permissible limits of size. The tolerance is an absolute value without sign and is specified as T. Allowable variation is normally specified as $\pm T/2$.

TROWELLING - working the unformed surface of fresh concrete to produce a smooth and dense finish.

WATER/CEMENTING MATERIAL RATIO - the ratio by mass of the amount of water to the total amount of water to the total amount of cementing material in a freshly mixed batch of concrete or mortar, preferably stated as a decimal. The water shall be exclusive of that absorbed by the aggregate.

WORKABILITY - the property of freshly mixed concrete or mortar that determines the ease and homogeneity with which it can be mixed, placed, compacted, and finished.

APPENDIX A

Figures

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Figure 1

Standard A 283 Concrete Testing Laboratory Type II with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Address:

Project Number: 104 - 8394

Date Tested: 90-01-17 **By:** JMW

Client: INNOVATIVE HOUSING GRANTS PRG. ALBERTA MUNICIPAL AFFAIRS.

Attention: MR. TERRY TOTH, P.ENG.

Sample Number: 3014. 1

Sample Description: BOTTOM ASH SUNDANCE POWER PLANT

Natural Moisture Content: 33. 1 %

Organic Content: %
State of Alaska Method

Plate Number:
Organic Impurities in Sands for Concrete

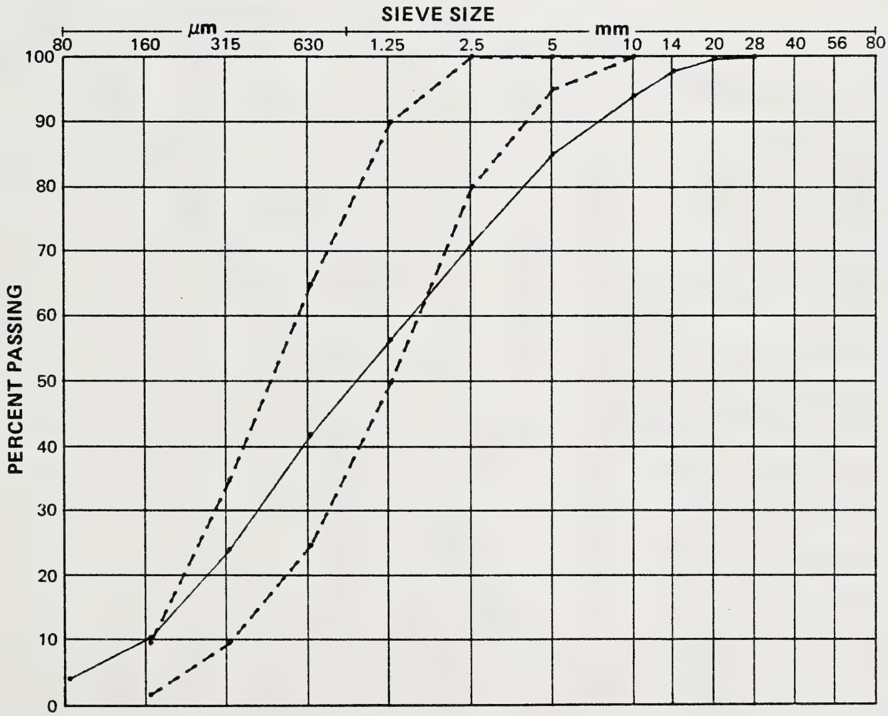
Bulk Relative Density:

Bulk Relative Density (SSD):

Apparent Relative Density:

Absorption: %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	100. 0
20 mm	99. 7
14 mm	97. 7
10 mm	94. 0
5 mm	85. 0
2.5 mm	71. 4
1.25 mm	56. 6
630 µm	42. 0
315 µm	24. 2
160 µm	10. 8
80 µm	4. 3
F.M.	3. 16



Remarks: RECEIVED 89-01-16
CSA FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JCL **P. Eng.**

EBA Engineering Consultants Ltd.

Figure 2

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Address:

Project Number: 104 - 8394

Date Tested: 90-01-17 **By:** JMW

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Attention: MR. TERRY TOTH, P.ENG.

Sample Number: 3014.2

Sample Description: BOTTOM ASH, SUNDANCE POWER PLANT, SCREENED ON 10mm SIEVE

Natural Moisture Content: 34.6 %

Organic Content: %
State of Alaska Method

Plate Number:
Organic Impurities in Sands for Concrete

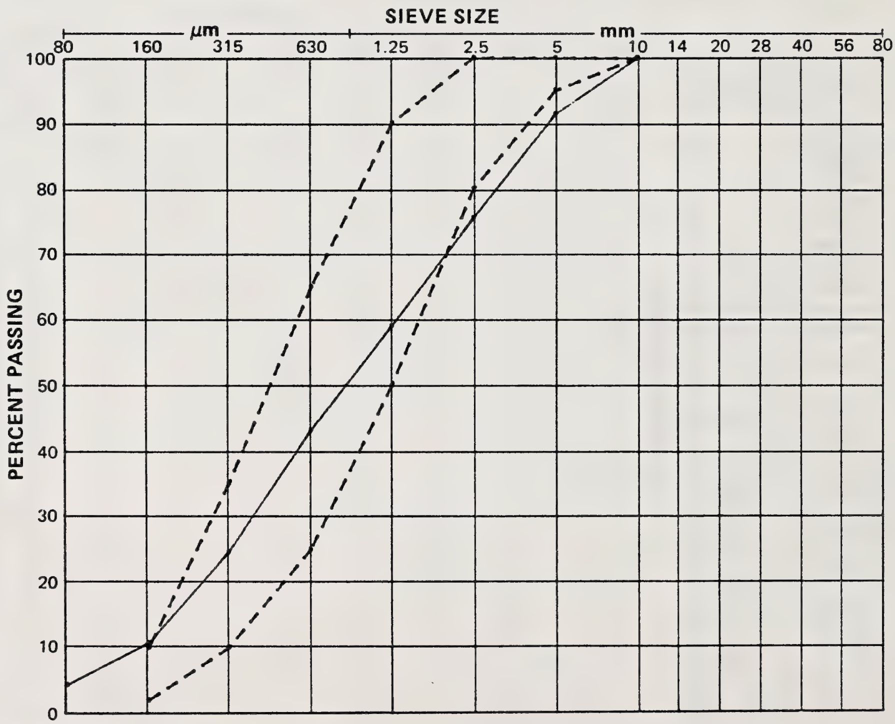
Bulk Relative Density: 1.98

Bulk Relative Density (SSD): 2.08

Apparent Relative Density: 2.24

Absorption: 5.9 %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	
14 mm	
10 mm	100.0
5 mm	91.4
2.5 mm	75.5
1.25 mm	59.1
630 µm	43.2
315 µm	24.6
160 µm	10.7
80 µm	4.2
F.M.	2.96



Remarks: RECEIVED 89-01-16
CSA FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JCR **P. Eng.**

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EBA Engineering Consultants Ltd.

Figure 3

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Sample Number: 3019

Address:

Sample Description: BOTTOM ASH, WABUMUM

Project Number: 104 - 8394

Natural Moisture Content: 35.2 %

Date Tested: 90-01-25 **By:** JMW

Organic Content: %
State of Alaska Method

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Plate Number:
Organic Impurities in Sands for Concrete

Bulk Relative Density:

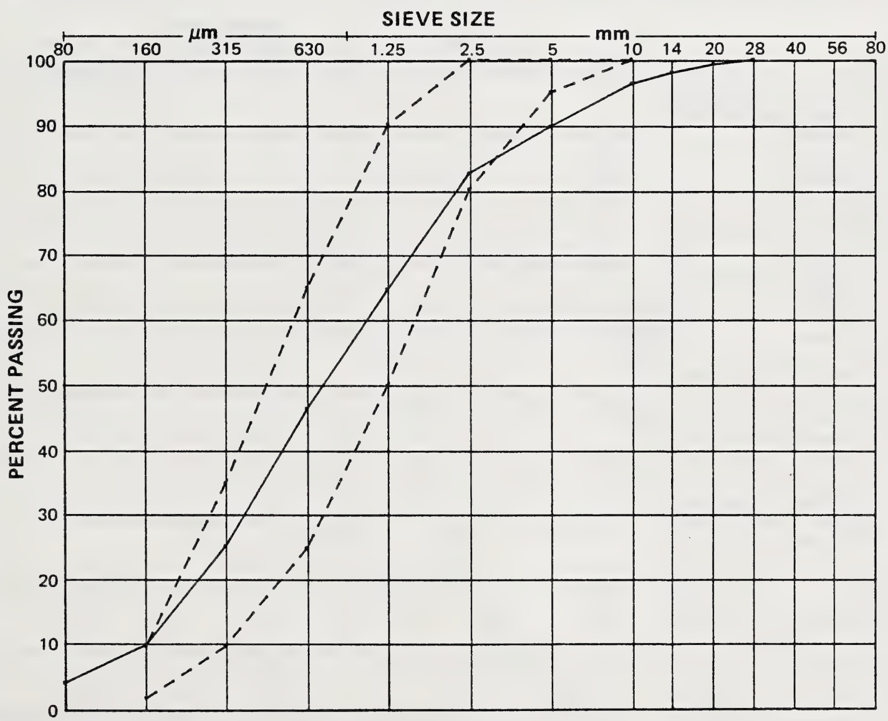
Attention: MR. TERRY TOTH, P.ENG.

Bulk Relative Density (SSD):

Apparent Relative Density:

Absorption: %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	100.0
20 mm	99.3
14 mm	97.9
10 mm	96.2
5 mm	89.6
2.5 mm	82.4
1.25 mm	64.7
630 µm	46.4
315 µm	25.2
160 µm	10.1
80 µm	4.2
F.M.	2.86



Remarks: RECEIVED 90-01-23
CSA FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JCK **P. Eng.**

2088

EBA Engineering Consultants Ltd.

Figure 4

Standard A 283 Concrete Testing Laboratory Type II with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Sample Number: 3036

Address:

Sample Description: FINE CONCRETE SAND.

Project Number: 104 - 8394

Natural Moisture Content: 4.6 %

Date Tested: 90-02-15 By: DJK

Organic Content: %
State of Alaska Method

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Plate Number: 3
Organic Impurities in Sands for Concrete

Bulk Relative Density: 2.59

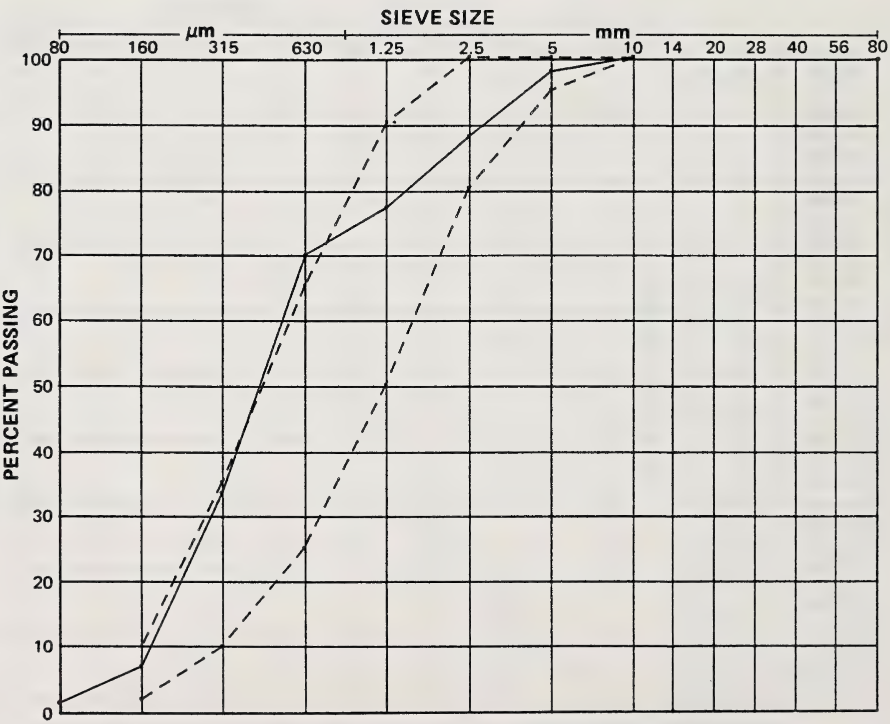
Attention: MR. D. TSANG, P. ENG.

Bulk Relative Density (SSD): 2.63

Apparent Relative Density: 2.69

Absorption: 1.4 %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	
14 mm	
10 mm	100.0
5 mm	97.7
2.5 mm	87.7
1.25 mm	76.8
630 µm	69.5
315 µm	33.3
160 µm	6.8
80 µm	1.2
F.M.	2.28



Remarks: CSA - A23.1 FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JDR P. Eng.

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EBA Engineering Consultants Ltd.

Figure 5

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Address:

Project Number: 104 - 8394

Date Tested: 90-03-08 **By:** JMW

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Attention: MR. D. TSANG, P. ENG.

Sample Number: 3045. 1

Sample Description: ELIMINATION SAND FROM GENERAL PIT.

Natural Moisture Content: 6. 1 %

Organic Content: %
State of Alaska Method

Plate Number:
Organic Impurities in Sands for Concrete

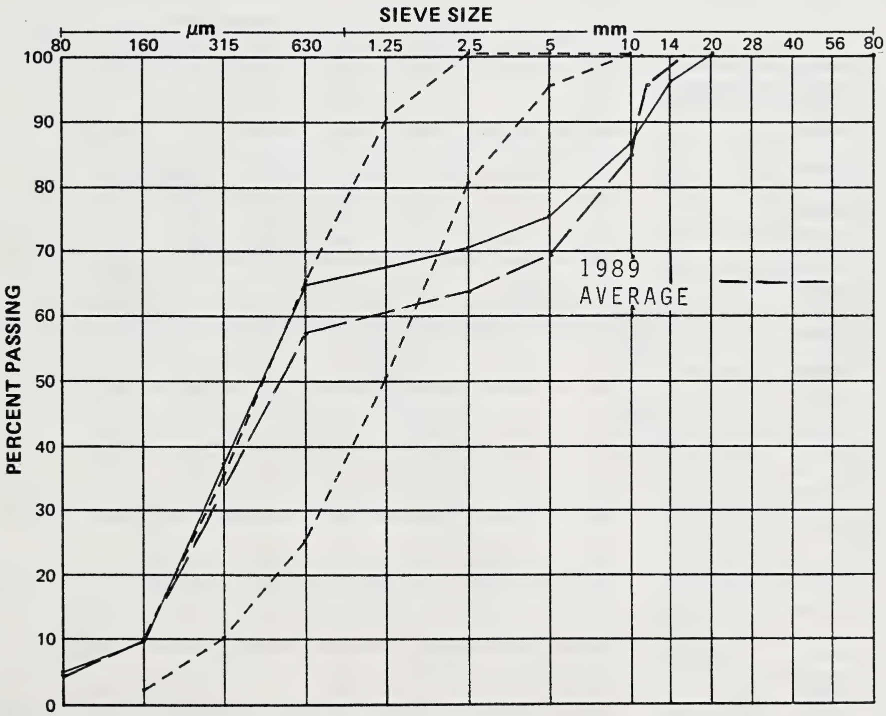
Bulk Relative Density:

Bulk Relative Density (SSD):

Apparent Relative Density:

Absorption: %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	100. 0
14 mm	95. 7
10 mm	86. 3
5 mm	74. 9
2.5 mm	70. 1
1.25 mm	67. 0
630 μm	64. 3
315 μm	36. 7
160 μm	9. 3
80 μm	4. 7
F.M.	2. 96



Remarks: CSA - A23. 1 FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JDR **P. Eng.**

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Figure 6

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Address:

Project Number: 104 - 8394

Date Tested: 90-03-08 **By:** JMW

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Attention: MR. D. TSANG, P. ENG.

Sample Number: 3045. 2

Sample Description: ELIMINATION SAND FROM GENERAL PIT.

Natural Moisture Content: %

Organic Content: %
State of Alaska Method

Plate Number: 3
Organic Impurities in Sands for Concrete

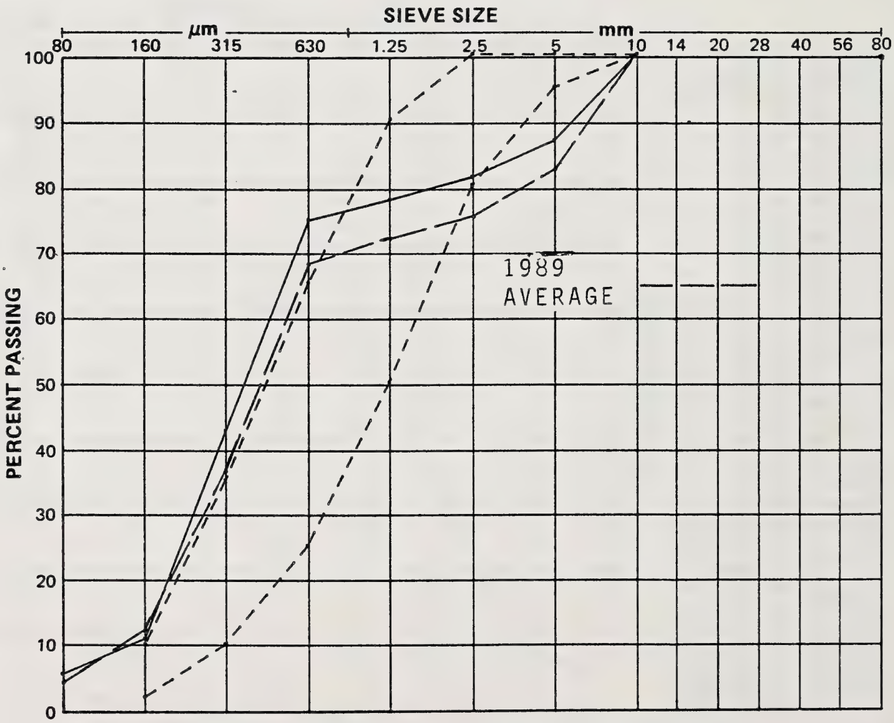
Bulk Relative Density: 2. 53

Bulk Relative Density (SSD): 2. 59

Apparent Relative Density: 2. 68

Absorption: 2. 2 %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	
14 mm	
10 mm	100. 0
5 mm	86. 8
2.5 mm	81. 2
1.25 mm	77. 6
630 μm	74. 5
315 μm	42. 5
160 μm	10. 8
80 μm	5. 4
F.M.	2. 27



Remarks: CSA-A23. 1 FINE AGGREGATE GRADING REQUIREMENTS.
THEORITICAL SPLIT: 10mm MINUS FRACTION.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JAR **P. Eng.**

2088

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Figure 7

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Address:

Project Number: 104 - 8394

Date Tested: 90-03-21 **By:** WGB

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Attention: MR. D. TSANG, P. ENG.

Sample Number: 3067. 1

Sample Description: ELIMINATION SAND FROM TBG PIT #21

Natural Moisture Content: 6. 2 %

Organic Content: %
State of Alaska Method

Plate Number: 3
Organic Impurities in Sands for Concrete

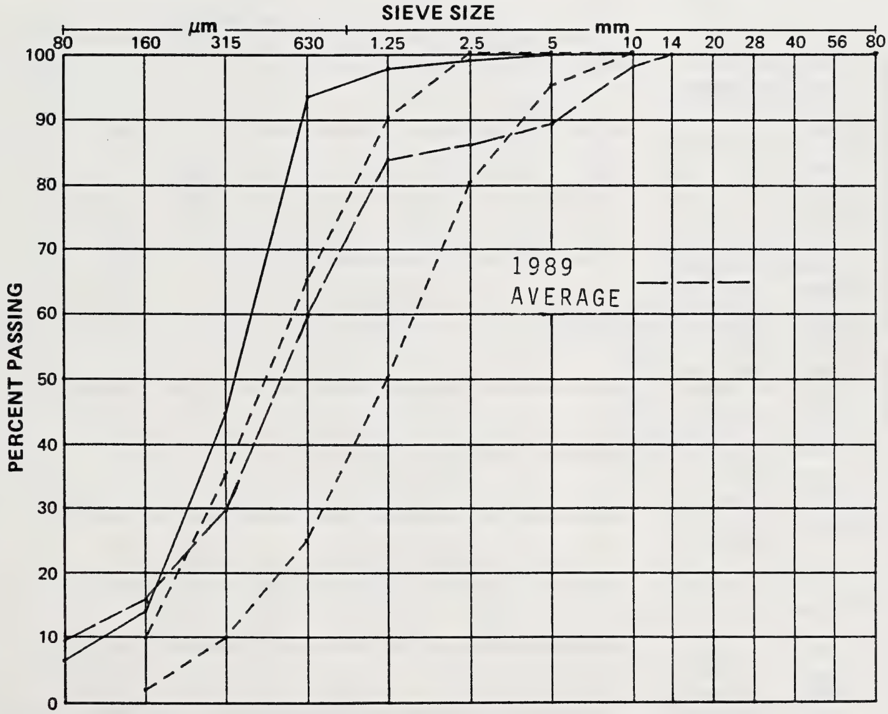
Bulk Relative Density: 2. 52

Bulk Relative Density (SSD): 2. 58

Apparent Relative Density: 2. 68

Absorption: 2. 3 %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	
14 mm	
10 mm	100. 0
5 mm	99. 5
2.5 mm	98. 7
1.25 mm	97. 4
630 µm	93. 0
315 µm	44. 4
160 µm	14. 0
80 µm	6. 3
F.M.	1. 53



Remarks: CSA - A23. 1 FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JOR **P. Eng.**

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The testing services reported herein have been performed by an EBA technician to recognized industry standards, unless otherwise noted. No other warranty is made. These data do not include or represent any interpretation or opinion of specification compliance or material suitability. Should engineering interpretation be required, EBA will provide it upon written request.

2088

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Figure 8

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Address:

Project Number: 104 - 8394

Date Tested: 91-01-25 **By:** JMW

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Attention: MR. D. TSANG, P. ENG.

Sample Number: 3019. 1

Sample Description: BOTTOM ASH, WABAMUN

Natural Moisture Content: %

Organic Content: %
State of Alaska Method

Plate Number:
Organic Impurities in Sands for Concrete

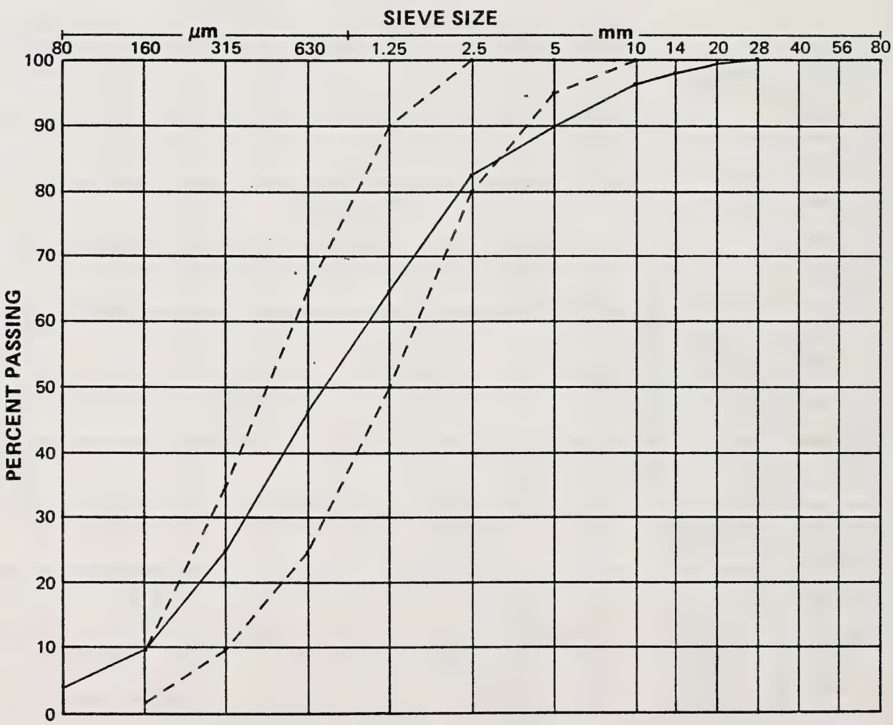
Bulk Relative Density:

Bulk Relative Density (SSD):

Apparent Relative Density:

Absorption: %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	100. 0
20 mm	99. 3
14 mm	97. 9
10 mm	96. 2
5 mm	89. 6
2.5 mm	82. 4
1.25 mm	64. 7
630 μm	46. 4
315 μm	25. 2
160 μm	10. 1
80 μm	4. 2
F.M.	2. 88



Remarks: RECEIVED ON 90-01-03
CSA-A23. 1 FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: **P. Eng.**

088

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Figure 9

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE
Sample Number: 3019.2

Address:
Sample Description: BOTTOM ASH, WABAMUN.

Project Number: 104 - 8394
Natural Moisture Content: 35.0 %

Date Tested: 90 02 02 **By:** MT
Organic Content: %
State of Alaska Method

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.
Plate Number: 5
Organic Impurities in Sands for Concrete

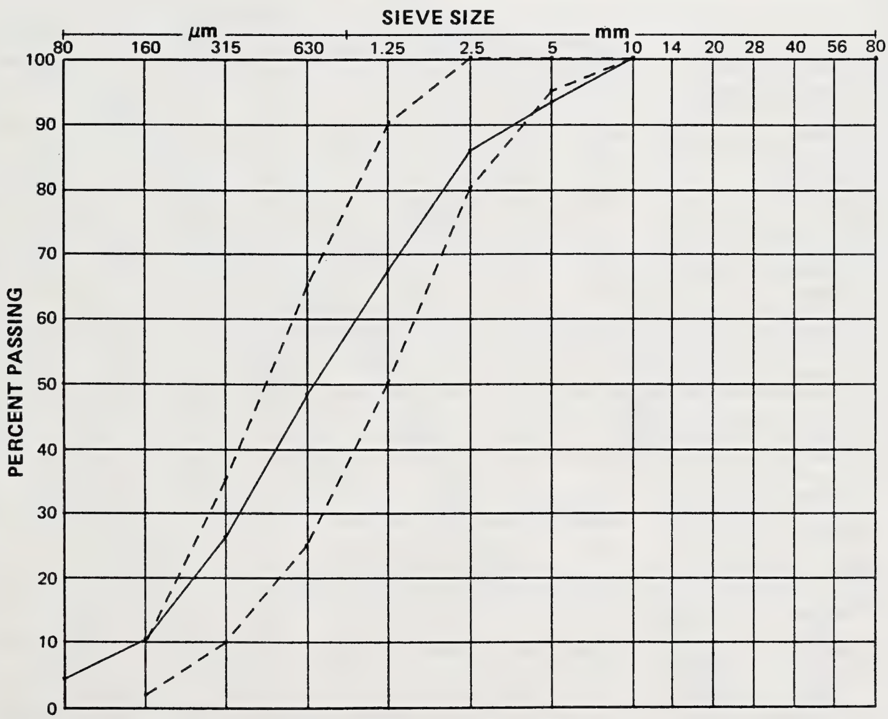
Bulk Relative Density: 1.90

Attention: MR. D. TSANG, P. ENG.
Bulk Relative Density (SSD): 1.98

Apparent Relative Density: 2.07

Absorption: 4.3 %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	
14 mm	
10 mm	100.0
5 mm	93.1
2.5 mm	85.7
1.25 mm	67.3
630 μm	48.2
315 μm	26.2
160 μm	10.5
80 μm	4.4
F.M.	2.69



Remarks: SCREENED ON 10 mm SIEVE
CSA-A23.1 FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JOR **P. Eng.**

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Figure 10

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Address:

Project Number: 104 - 8394

Date Tested: 90-30-20 By: MT

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Attention: MR. D. TSANG, P. ENG.

Sample Number: 3063. 1

Sample Description: BOTTOM ASH, WABAMUN

Natural Moisture Content: 35. 1 %

Organic Content: %
State of Alaska Method

Plate Number:
Organic Impurities in Sands for Concrete

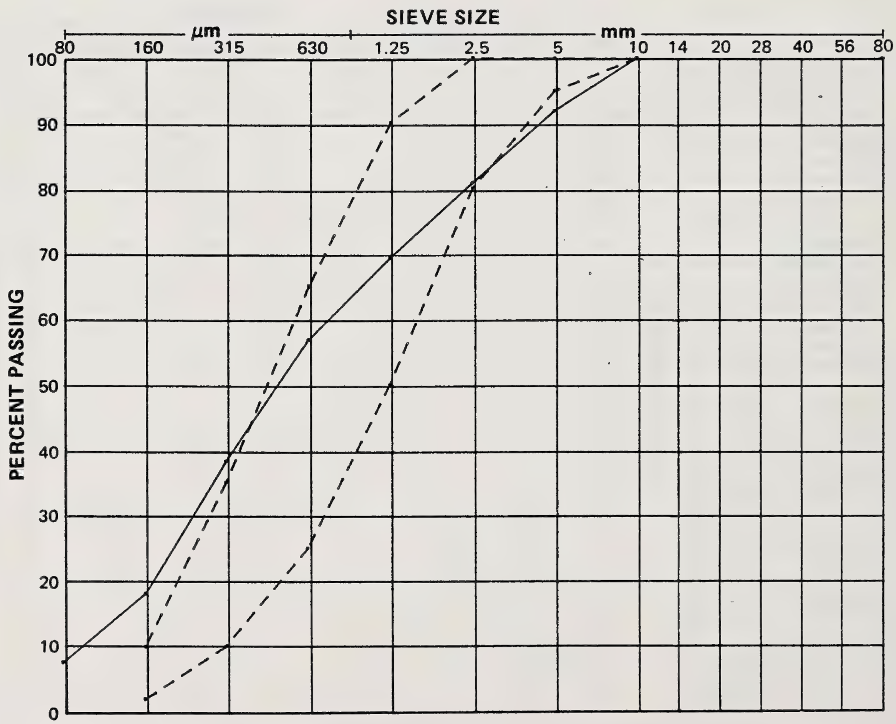
Bulk Relative Density:

Bulk Relative Density (SSD):

Apparent Relative Density:

Absorption: %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	
14 mm	
10 mm	100. 0
5 mm	91. 9
2.5 mm	80. 8
1.25 mm	69. 3
630 μm	56. 8
315 μm	38. 1
160 μm	17. 9
80 μm	7. 5
F.M.	2. 45



Remarks: SAMPLED PRIOR TO MIXING
CSA-A23. 1 FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: P. Eng.

EBA Engineering Consultants Ltd.

Figure 11

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Sample Number: 3063.2

Address:

Sample Description: BOTTOM ASH, WABAMUN.

Project Number: 104 - 8394

Natural Moisture Content: 52.7 %

Date Tested: 90-06-20 **By:** MAH

Organic Content: %
State of Alaska Method

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Plate Number:
Organic Impurities in Sands for Concrete

Bulk Relative Density:

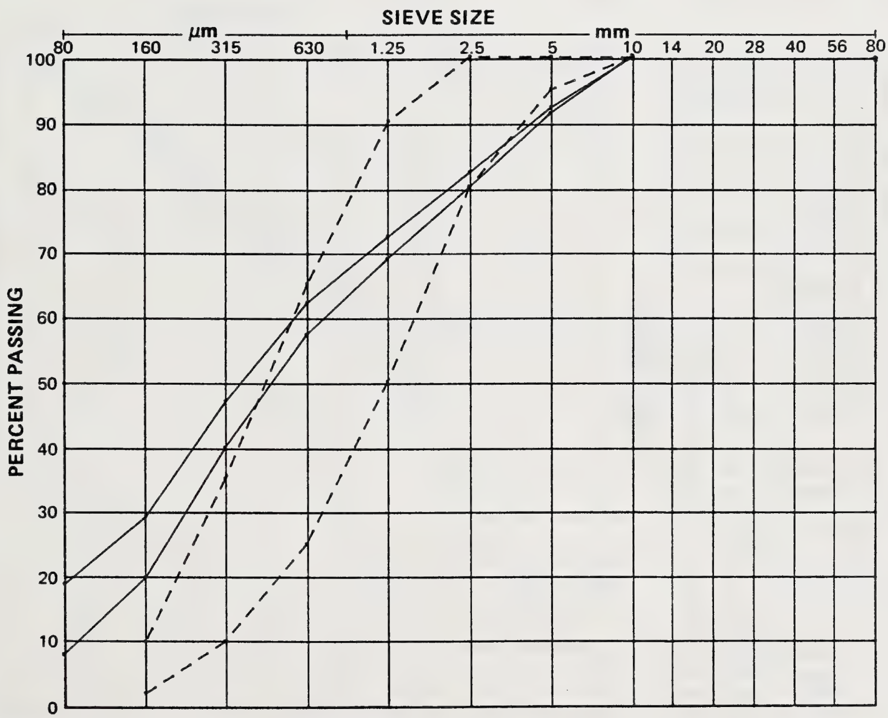
Attention: MR. D. TSANG, P. ENG.

Bulk Relative Density (SSD):

Apparent Relative Density:

Absorption: %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	
14 mm	
10 mm	100.0
5 mm	92.2
2.5 mm	82.2
1.25 mm	72.3
630 μm	62.1
315 μm	46.8
160 μm	29.2
80 μm	18.7
F.M.	2.15



Remarks: SAMPLED AFTER 10 Min. MIXING.
CSA - A23.1 FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JDR **P. Eng.**

2088

EBA Engineering Consultants Ltd.

Figure 12

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Sample Number: 3063. 3

Address:

Sample Description: BOTTOM ASH. WABAMUN.

Project Number: 104 - 8394

Natural Moisture Content: 53. 6 %

Date Tested: 90 03 20 **By:** MAH

Organic Content: %
State of Alaska Method

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Plate Number:
Organic Impurities in Sands for Concrete

Bulk Relative Density:

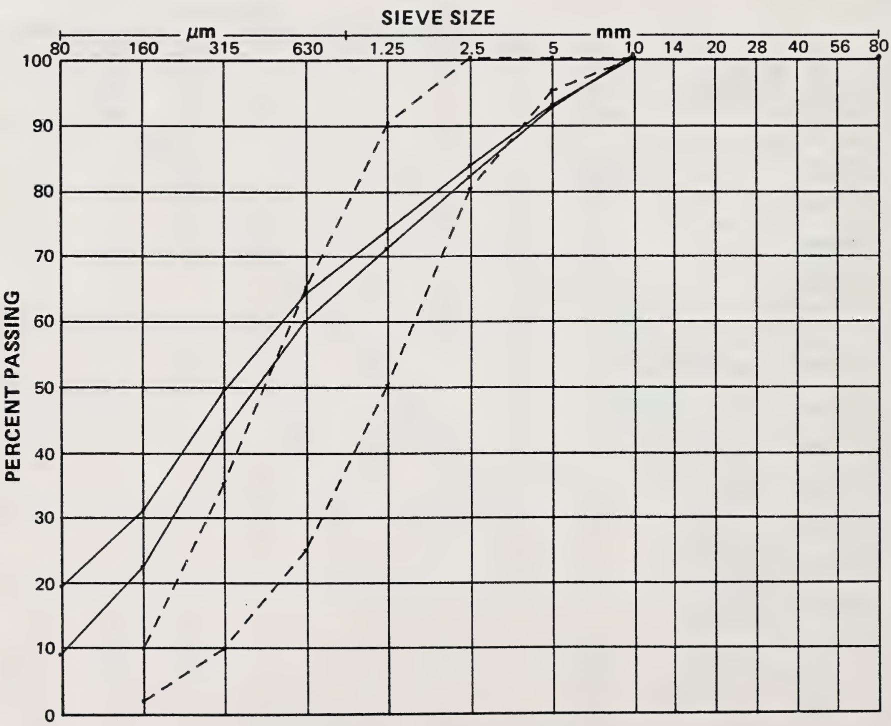
Attention: MR. D. TSANG, P. ENG.

Bulk Relative Density (SSD):

Apparent Relative Density:

Absorption: %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	
14 mm	
10 mm	100. 0
5 mm	92. 8
2.5 mm	83. 5
1.25 mm	73. 8
630 μm	64. 1
315 μm	49. 2
160 μm	31. 2
80 μm	19. 4
F.M.	2. 05



Remarks: SAMPLED AFTER 30 Min. MIXING
CSA-A23. 1 FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JDR **P. Eng.**

EBA Engineering Consultants Ltd.

Figure 13

Standard A 283
Concrete Testing
Laboratory Type II
with all Options

AGGREGATE ANALYSIS REPORT
(CONCRETE AGGREGATE)

Project: OPTIMIZATION OF FILLCRETE

Address:

Project Number: 104 - 8394

Date Tested: 90-03-20 **By:** MAH

Client: INNOVATIVE HOUSING GRANTS PRG.
ALBERTA MUNICIPAL AFFAIRS.

Attention: MR. D. TSANG, P. ENG.

Sample Number: 3063. 4

Sample Description: BOTTOM ASH, WABAMUN

Natural Moisture Content: 51. 4 %

Organic Content: %
State of Alaska Method

Plate Number:
Organic Impurities in Sands for Concrete

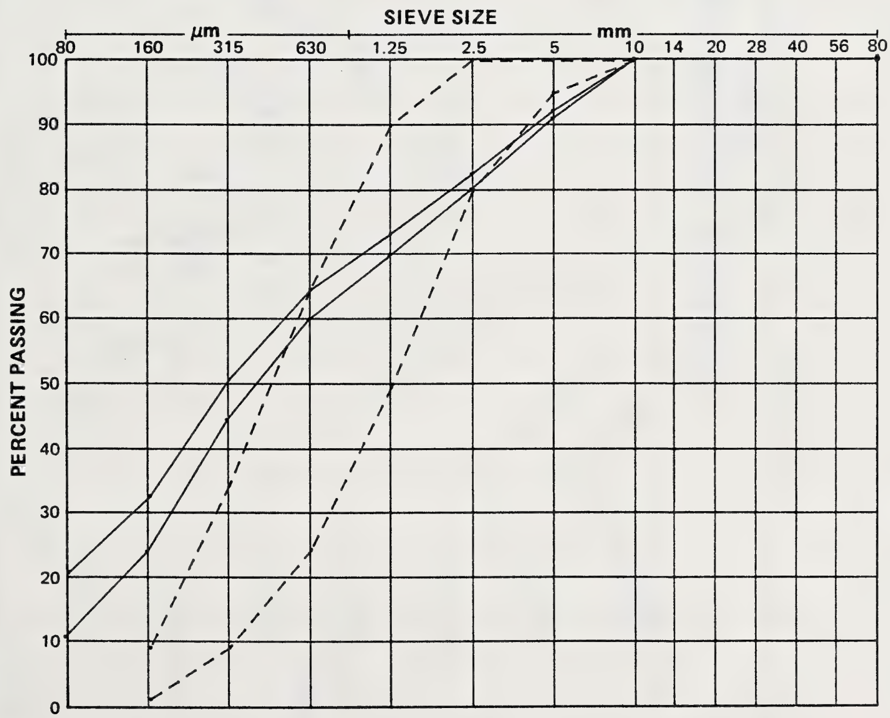
Bulk Relative Density:

Bulk Relative Density (SSD):

Apparent Relative Density:

Absorption: %

Sieve	% Passing
80 mm	
56 mm	
40 mm	
28 mm	
20 mm	
14 mm	
10 mm	100. 0
5 mm	92. 0
2.5 mm	82. 4
1.25 mm	73. 3
630 μm	64. 7
315 μm	51. 0
160 μm	33. 2
80 μm	21. 6
F.M.	2. 03

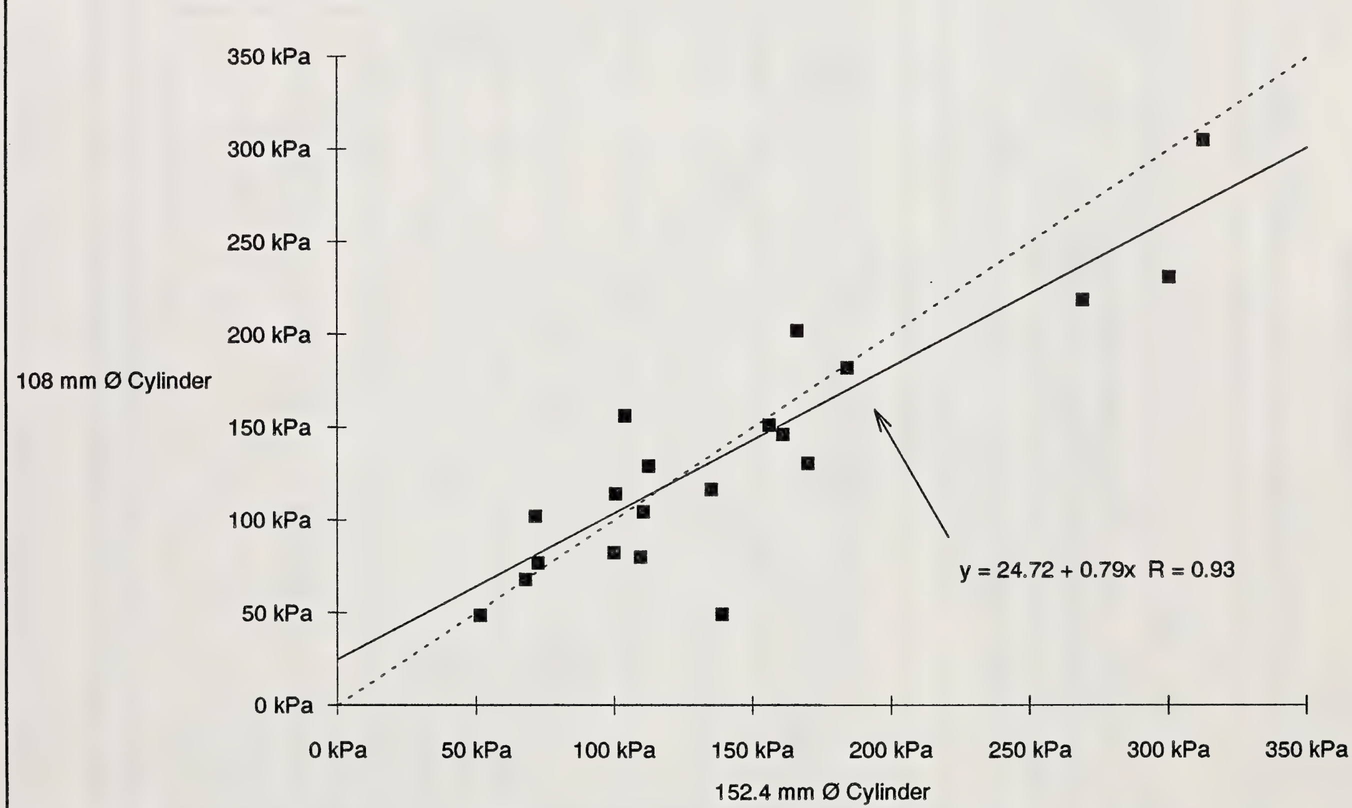


Remarks: SAMPLED AFTER 50 Min. MIXING.
CSA-A23. 1 FINE AGGREGATE GRADING REQUIREMENTS.

NOTE: A testing service only has been provided in reporting these test data. Engineering interpretation or evaluation of such test data will be provided upon request.

Reviewed By: JDR **P. Eng.**

Figure 14: 7-Day Compressive Strength Comparison



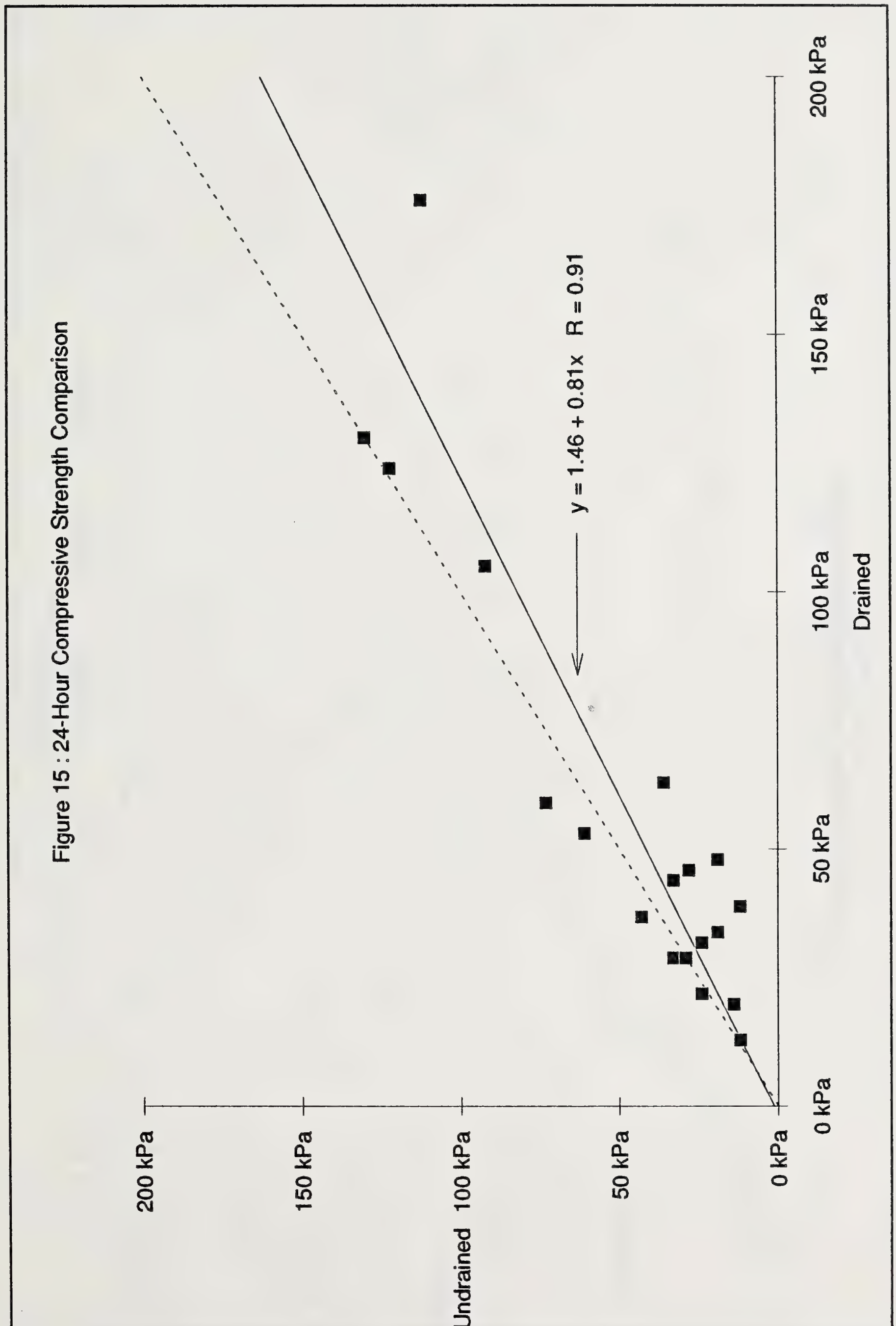


Figure 15 : 24-Hour Compressive Strength Comparison

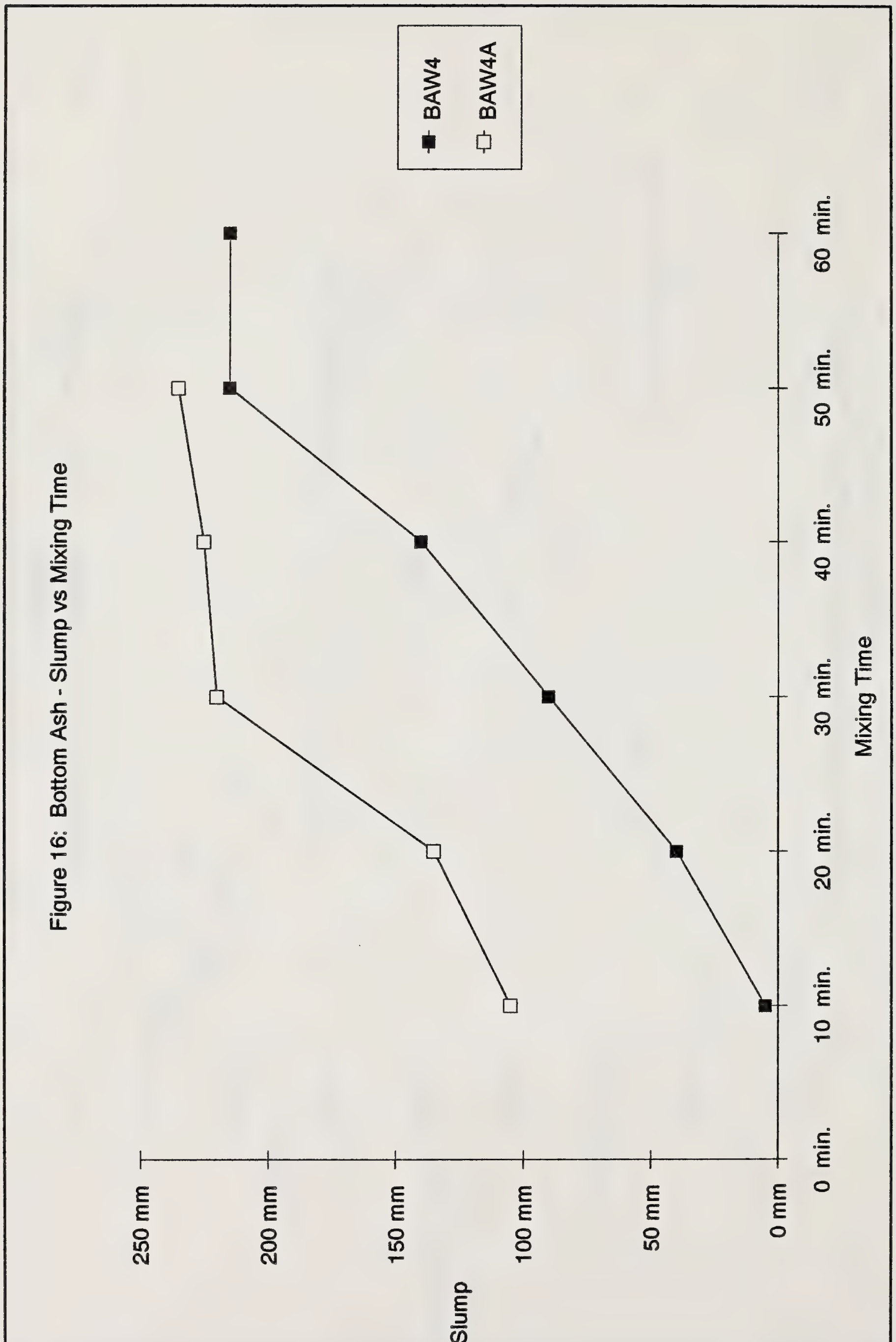


Figure 16: Bottom Ash - Slump vs Mixing Time

Figure 17: Compressive Strength FCA - No Admixtures

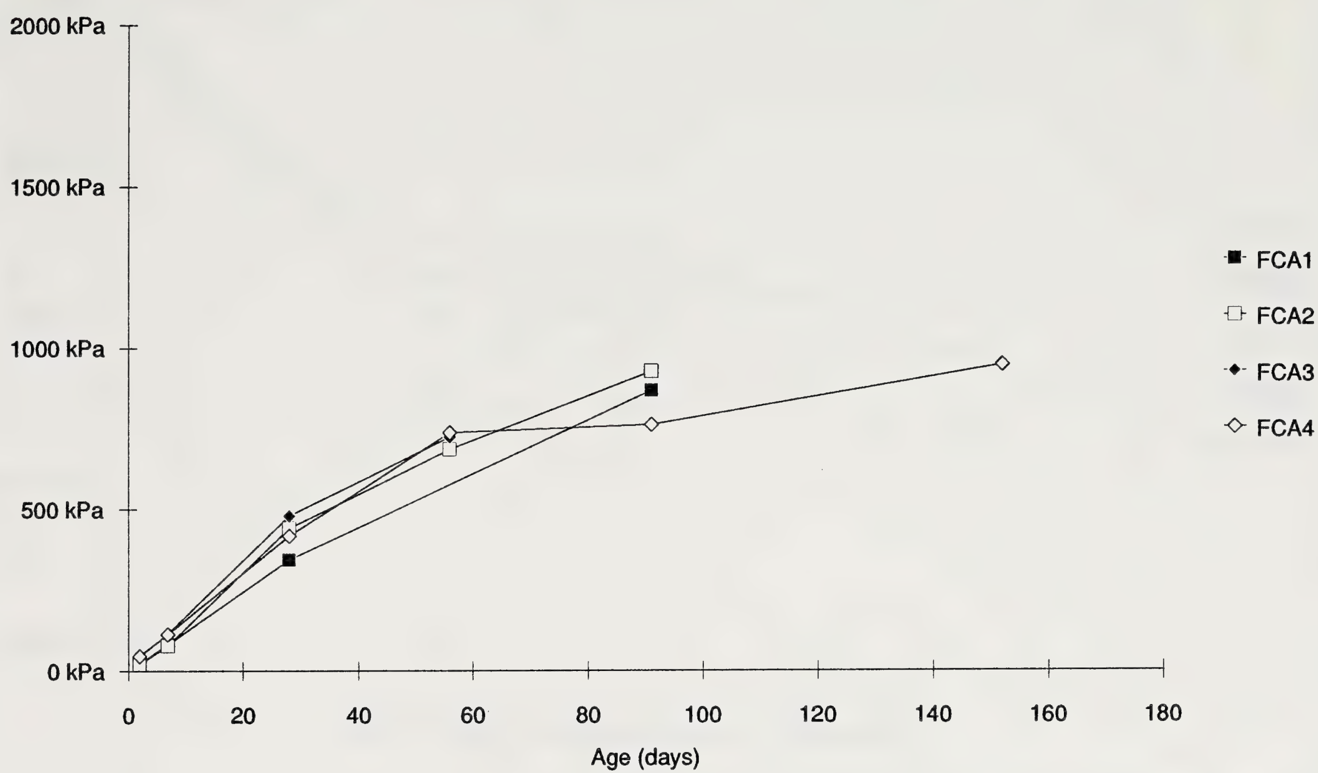


Figure 18: Compressive Strength FCA - Air Entrained

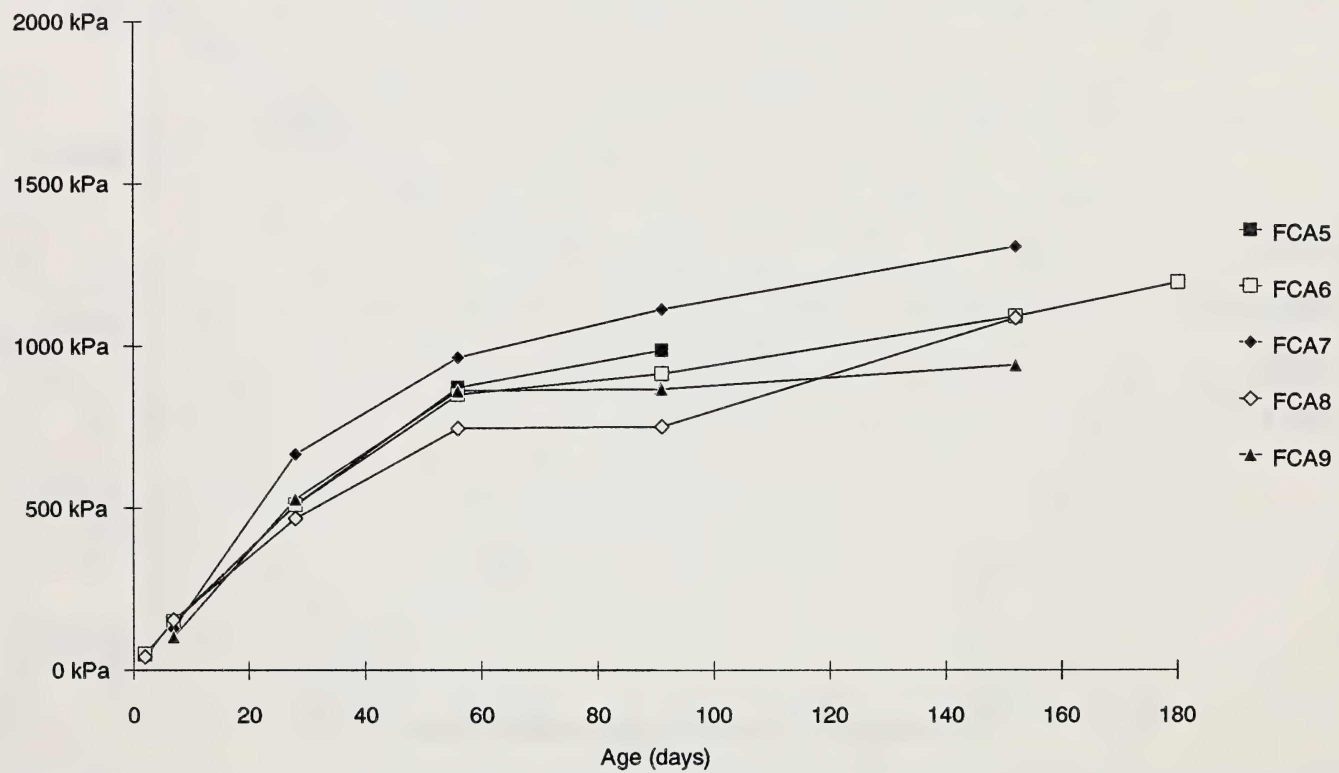


Figure 19: Compressive Strength FCA - Air Entrained, Water Reducer

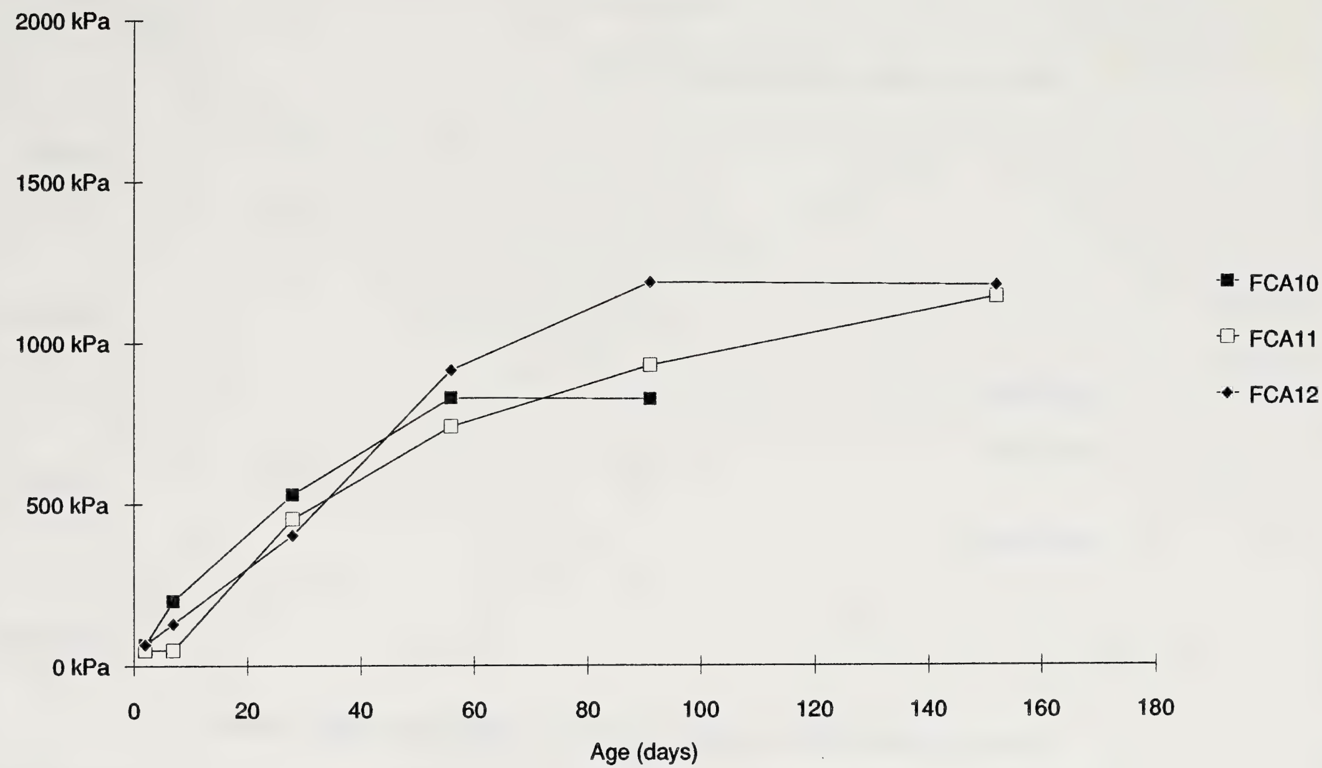
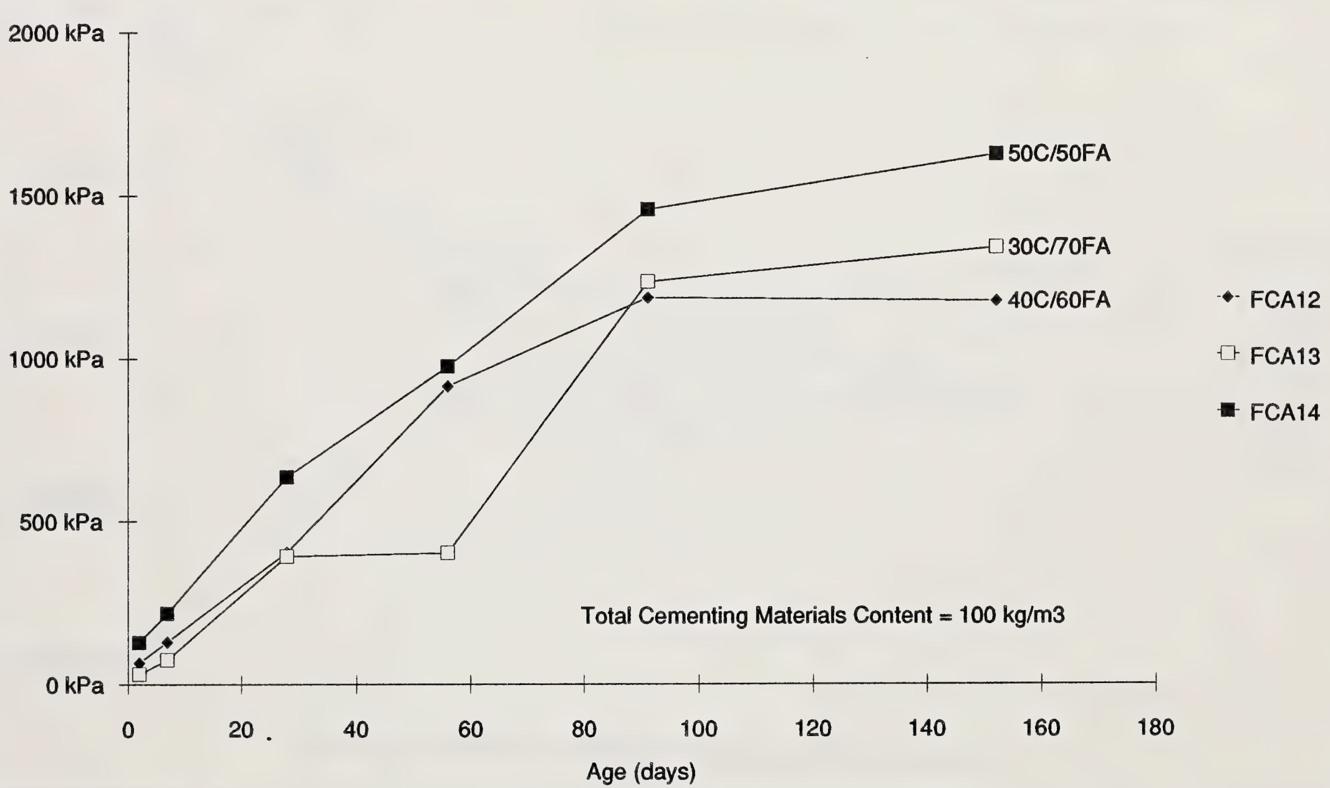


Figure 20: Compressive Strength FCA - Varied Cement (C) and Flyash (FA) Content



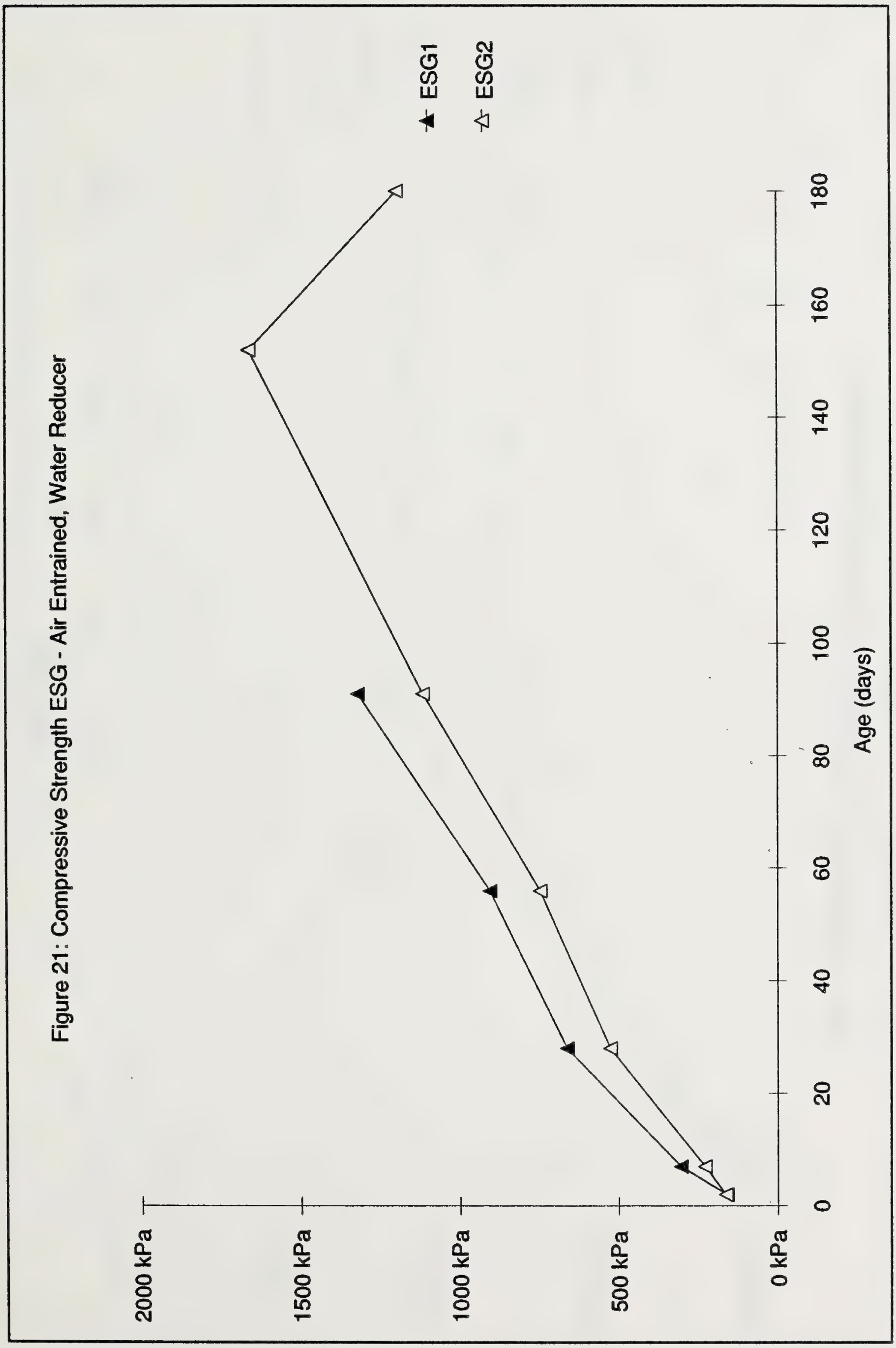


Figure 21: Compressive Strength ESG - Air Entrained, Water Reducer

Figure 22: Compressive Strength ESS - Air Entrained, Water Reducer

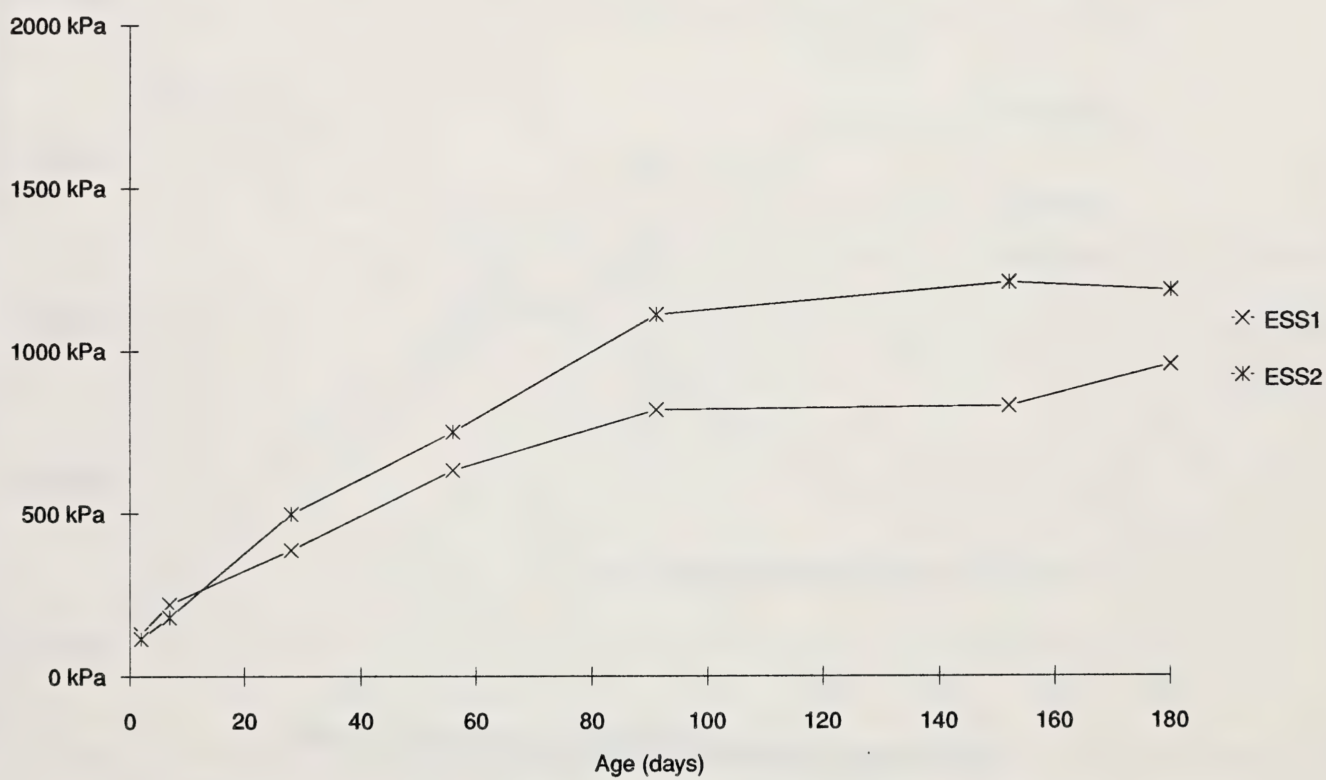


Figure 23: Compressive Strength - Natural Aggregates

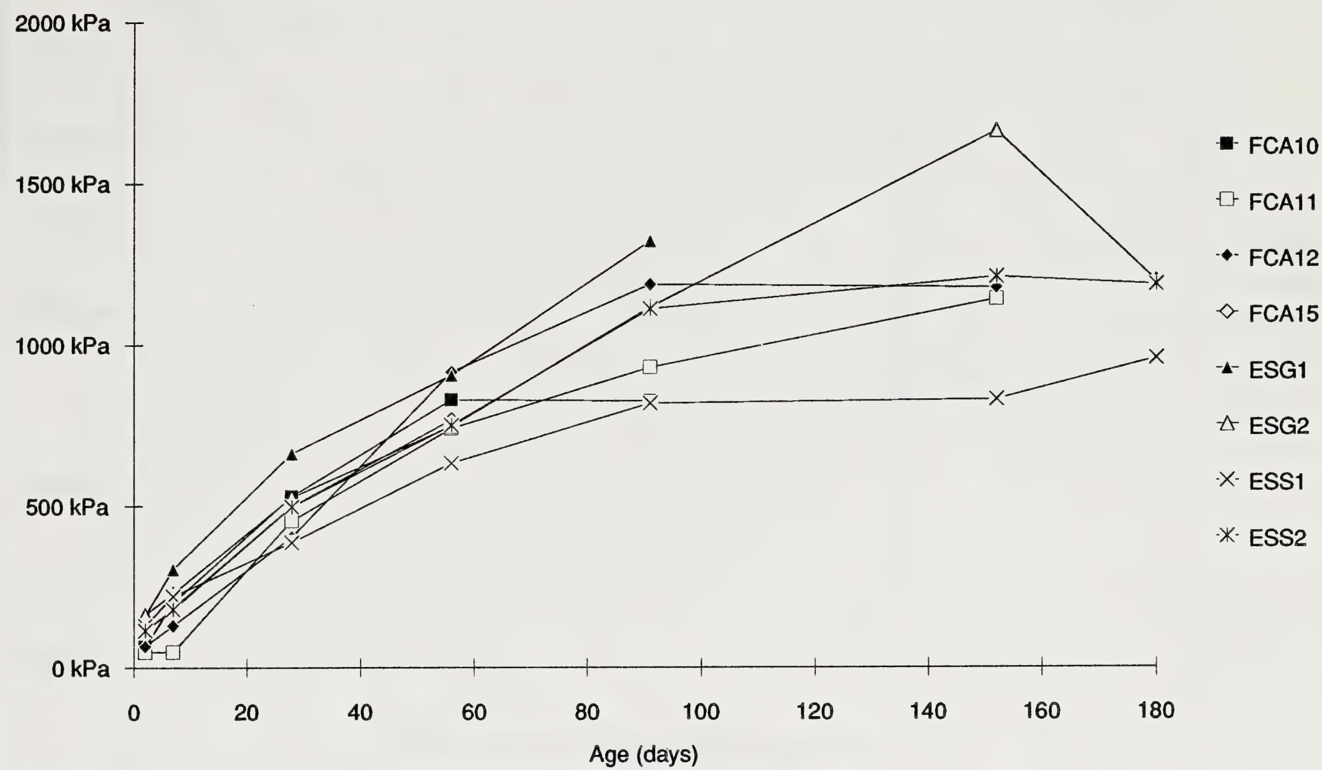
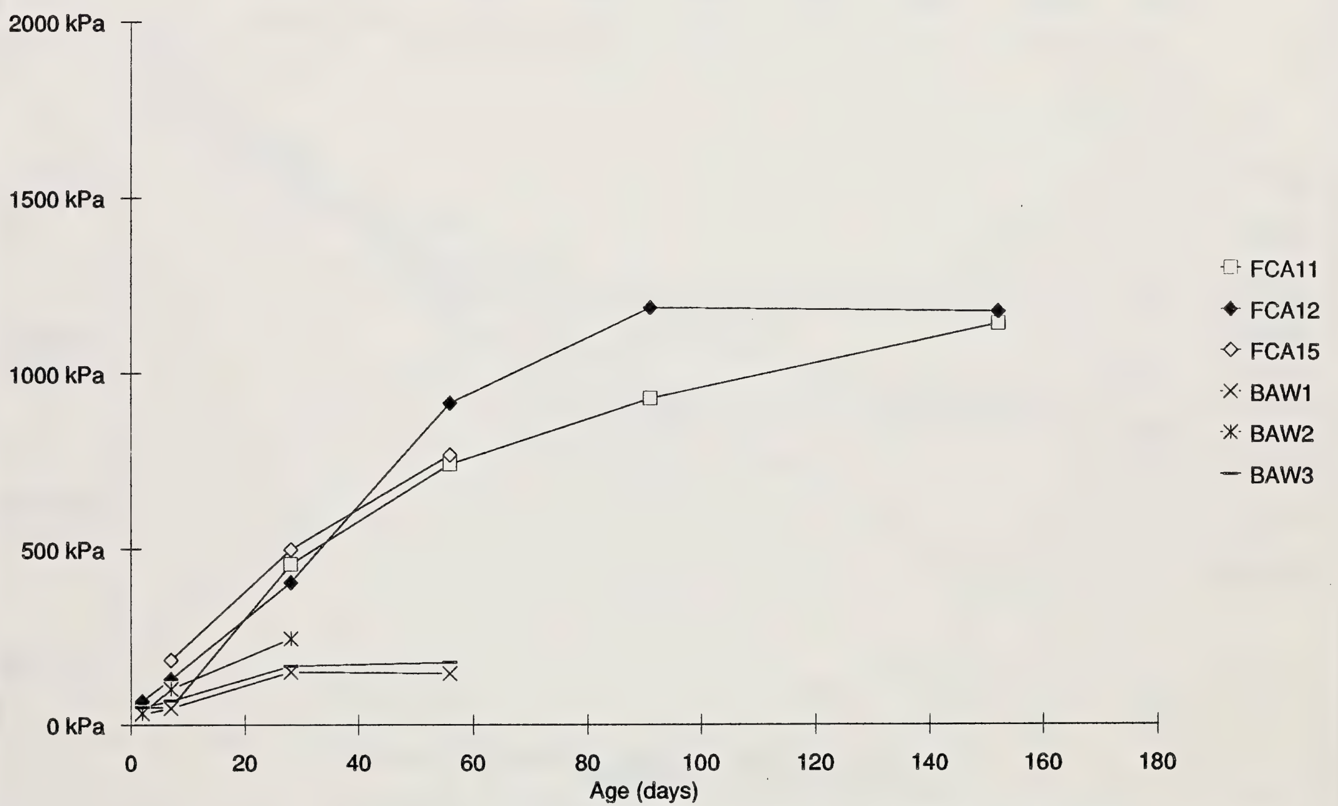


Figure 24: Compressive Strength - FCA vs BAW



APPENDIX B

Generic Fillcrete Specifications

APPENDIX B

Generic Fillcrete Specifications

The following sections provide generic specifications for the production of fillcrete.

1.0 Reference Standards

.1 Perform fillcrete work in accordance with the following standards except where specified otherwise.

.1 Concrete Materials and Methods of Concrete Construction - CAN/CSA - A23.1 M90.

.2 Methods of Test for Concrete - CAN/CSA - A23.2 M90.

1.1 Inspection and Testing

.1 Fillcrete work may be tested by a testing firm retained by the Owner.

.2 Submit samples of fine aggregate along with proposed fillcrete mix design to the testing firm's laboratory.

.3 Provide casual labour to the testing firm's field personnel for the purpose of obtaining and handling sample materials.

.4 Advise testing firm in advance of fillcrete placement.

.5 Provide and maintain facilities at the site for storage of fillcrete test cylinders for the first 24 hours.

.6 Provide copies of mill test reports of cement as required.

.7 Testing firm will take three test cylinders from each 150 m^3 of fillcrete, or fraction thereof, placed in any one day.

.8 Testing firm will moist cure and test one cylinder in 2 days and the two cylinders in 28 days.

.9 Testing firm will make at least one slump test and one entrained air test for each set of test cylinders taken.

2.0 Products

2.1 Fillcrete Materials

.1 Portland Cement: to CAN3-A5-M83 Type 10 (Normal).

.2 Water: to CAN/CSA - A23.1 M90.

.3 Fine Aggregate: mixture of natural gravel, crushed gravel or crushed stone, and natural or crushed sand meeting the following gradation limits

Sieve Size (mm)	Percent Passing by weight
14	100
10	90 - 100
5	80 - 100
0.315	10 - 50
0.080	0 - 10

The aggregate grading shall be sufficient to produce a fillcrete mix of adequate workability while minimizing segregation during and immediately after placement.

.4 Air Entraining Admixtures: to CAN3 - A266.1 M78.

.5 Chemical Admixtures: to CAN3 - A266.2 M78.

.6 Pozzolanic Mineral Admixtures: to CAN3 - A266.3 M78.

2.2 Fillcrete Mixes

.1 Supply Fillcrete with a minimum 2-day compressive strength of 50 kPa and/or capable of supporting construction traffic with no measurable deformation. The 28-day compressive strength shall not exceed 600 kPa. Compressive strength at 6 months shall not exceed 1500 kPa.

.2 Fillcrete shall be placed at a slump of 75 to 125 mm. The maximum slump of the fillcrete mix shall be limited to avoid excessive bleeding and segregation of the mix.

.3 Fillcrete shall be placed with a minimum entrained air content of 4.0 percent.

3.0 Execution

3.1 Placement

.1 Fillcrete to be placed in accordance with CAN/CSA - A23.1 M90, Concrete Materials and Methods of Construction

.2 Fillcrete to be consolidated as required to fill overhangs, voids behind shoring, etc. Consolidation may be accomplished by means of puddling sticks, internal vibration or other approved means.

2.0 Products

2.1 Fillcrete Materials

Sieve Size (mm)	Percent Passing by weight
14	100
10	90 - 100
5	80 - 100
0.315	10 - 80
0.080	0 - 10

The aggregate grading shall be sufficient to produce a Fillcrete mix of adequate workability while minimizing segregation during and immediately after placement.

.4 Air Entraining Admixtures: to CAN3 - A266.1 M78.

.5 Chemical Admixtures: to CAN3 - A266.2 M78.

.6 Pozzolanic Mineral Admixtures: to CAN3 - A266.3 M78.

2.2 Fillcrete Mixes

.1 Supply Fillcrete with a minimum 2-day compressive strength of 50 kPa and/or capable of supporting construction traffic with no measurable deformation. The 28-day compressive strength shall not exceed 800 kPa. Compressive strength at 6 months shall not exceed 1500 kPa.

.2 Fillcrete shall be placed at a slump of 75 to 125 mm. The maximum slump of the Fillcrete mix shall be limited to avoid excessive bleeding and segregation of the mix.

.3 Fillcrete shall be placed with a minimum entrained air content of 4.0 percent.